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Assessing the Materiality of Nature-Related Financial Risks for the UK

University of Reading

UN environment programme WCMC

National Institute of Economic and Social Research

April 2024

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Acknowledgements
We wish to thank the Analysis Advisory Committee (Rhian Mari-Thomas, Martin Booth, David Craig, Neha Dutt, Carlos Martin Tornero) for their guidance and support. We gratefully acknowledge the contributions of our wider teams as part of the UK Integrating Finance and Biodiversity Programme, including Paula Harrison (UKCEH), James Bullock (UKCEH), Michael Obersteiner (Oxford), Anna Freeman (Oxford), Tom Harwood (Oxford), Emma O'Donnell (Oxford), Estelle Paulus (Oxford) and Roberto Spacey Martin (Oxford). UNEP-WCMC acknowledge contributions of Ian Ondo, Qian Feng, Sarah Pickering, Corli Pretorius, Neville Ash, Simon Croft (SEI York) and Charlie Egan (SEI York). Thank you also to the financial institutions that contributed to the co-development of scenarios and analysis through many meetings and roundtable discussions during 2023/4, in particular thanks to the members of the UK Climate Financial Risk Forum Resilience Working Group and Nature Sub-Group, with particular gratitude to the working group chairs Billy Suid (Barclays) and Sandy Trust (M&G). We also thank the Taskforce on Nature-Related Financial Disclosures (Emily McKenzie and team) and Charlie Dixon of the Green Finance Institute for their reviews and inputs. We thank the following experts for contributions to this report through providing scores and comments on the evidence in the UK-NRRI: Tom Breeze (University of Reading); James Bullock (UKCEH), Rebecca English (Lloyds); Pete Falloon (Met Office); Matthew Fisher (Imperial College London); Anna Freeman (University of Oxford); Mike Garratt (University of Reading); Helena Gauterin (The OEP); Mike Goodman (University of Reading); Paula Harrison (UKCEH); Tom Harwood (University of Oxford); Hyejin Kim (UKCEH); Sarah Moller (University of York); Emma Mutch (Defra); Silviu Petrovan (University of Cambridge); Vanessa Pilley (Defra); Khalid Rashid (HSBC); Victoria Robinson (Defra); Maria Shahgedanova (University of Reading); Stephen Thackeray (UKCEH), Julia Touza (University of York); Phil Tovey (Defra); Andrew Wade (University of Reading); Dr David Willer (University of Cambridge). We are also grateful to Akaraseth Puranasamriddhi, André Dornelles, Tosca Tindall and Melissa Guckenberger at the University of Oxford for their research assistance. We gratefully acknowledge the funding support of the European Climate Foundation, the Esmee Fairbairn Foundation, the Department for Environment, Food and Rural Affairs, as well as the UKRI Integrating Finance and Biodiversity Programme, and the Oxford Martin Systemic Resilience Programme.

Contributing Partners

Established in 2019, the **Green Finance Institute** is accelerating the transition towards an environmentally sustainable and resilient economy by catalysing investment in net zero and nature positive outcomes. Uniquely positioned at the nexus of the public and private sectors, the Green Finance Institute is the UK's principal forum for innovation in green finance.

The Environmental Change Institute at the **University of Oxford** was established in 1991 to organise and promote interdisciplinary research on the nature, causes and impact of environmental change and to contribute to the development of management strategies for coping with future environmental change. **Dr Nicola Ranger** is Director for Greening Finance for Nature of the UKRI Integrating Finance and Biodiversity (IFB) Programme and directs the **Resilient Planet Finance Lab** at the Environmental Change Institute.

The **University of Reading** has been at the forefront of UK higher education for nearly a century. Over the decades we have become innovators and pioneers, pushing academic boundaries and leading social change. **Prof Tom Oliver** is a Professor of Applied Ecology and Research Dean for Environment at the University of Reading.

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The University of Oxford, University of Reading, UNEP-WCMC and the UK Centre for Ecology and Hydrology are all partners to the **UKRI** Integrating Finance and Biodiversity Programme's **Greening Finance for Nature** initiative, which seeks to provide data, analytics and evidence to support financial institutions to integrate nature within financial decision making.

Foreword

Intuitively we know that the continued degradation of nature harms our collective prosperity. Perhaps we witness first-hand how water pollution doesn't just destroy the natural environment we love, but how it also negatively impacts our fisheries and our tourism sector. Or, maybe we see that the ongoing decline of soil health is lowering the resilience of our farmers, as well as increasing prices and impacting food security. Or we are acutely aware that zoonotic diseases (like COVID-19), air pollution and reduced access to green spaces, are impacting our physical and mental health, reducing our workforce and putting a strain on our national health system.

These nature-related financial and economic risks are multiple - driven by land and sea use change, pollution, direct exploitation, invasive species as well as climate change. They also go beyond those created by physical damage to our environment, and extend to transition risks and litigation risks experienced by companies.

As one of the most nature-depleted countries in world, these risks are ones that the UK can ill afford to ignore. So long as these risks remain unmeasured, however, they stay unrecognised – neither explicitly captured within prudential policies or fiscal risk management frameworks, nor comprehensively included within our national risk registers.

And while this remains the case, we are told by companies, by governments, that nature can wait – that our attention must focus instead on climate targets, or, more precisely, GHG emissions reduction targets. In the meantime, nature degradation and nature-related financial risks continue at pace and unchecked.

If there is one message to take from this report it is this: nature cannot wait. The analysis presented within these pages, seeks to move us beyond what we might know intuitively, to move us beyond understanding our dependency on nature, and instead to quantify for the first time the cost to the UK economy of nature's destruction – to quantify nature-related risks.

The results are beyond what we imagined. These nature-related risks, driven by water shortages and pollution, soil health decline, and biodiversity loss, and compounded with inevitable shocks such as drought, may have a greater impact on our GDP than the Global Financial Crisis. As the risk of an anti-microbial resistance-driven pandemic increases, we may even see a hit to our GDP greater than that experienced during COVID-19.

These are not far-off risks. They are happening now, and they could occur all at once. These are conservative estimates – and they are commensurate with the financial risks caused by GHG emissions. Furthermore, it is not only our economy that we are sabotaging. Through the analysis of our financial institutions' loan exposure to companies in sectors with high nature-related risk, we also find our very financial stability may be at risk.

Armed with this evidence, there is now no excuse for delay. We must swiftly transition our economic and financial system to one that values and invests in our natural environment.

To do so, we must first stop treating nature and climate as separate issues. One underpins the other. Even to regard climate and nature as 'two sides of the same coin' does not do justice to their degree of interrelatedness. An integrated and holistic approach is now needed.

Tackling climate change means reducing emissions **and** ensuring our natural environment is thriving. It means ensuring that our forests, peatlands, hedgerows, wetlands, grasslands, soils, waterways, and oceans are healthy and therefore effective in mitigating and reducing climate change impacts. This means also recognising that the millions of species that live in these habitats – and their survival – are integral to those efforts. The interconnections and feedback loops between climate and nature are complex, numerous, and reinforcing.

Secondly, we must recognise that these risks cannot be tackled by an individual country alone. Half of our nature-related financial risks are international. Our human interrelatedness, our economic interrelatedness means that we must not only restore and protect nature here in the UK, but also work internationally, collaborating to meet the goals of the Global Biodiversity Framework.

The transition required is, of course, daunting. But within these pages we are also presented with an opportunity.

We could continue as usual, knowing now for certain that, in destroying our natural environment, we are also destroying our own future prosperity,

Or…

We can set a new course; one in which we value and invest in nature, and in doing so, create a future in which we can better ensure that our companies succeed, that our financial system remains strong, that our food system is secure, that our health and well-being is supported, and that our economy thrives.

Helen Avery
Director, Nature Programmes, Green Finance Institute

Executive Summary

At least half of global GDP is moderately or highly directly dependent on nature, and ultimately there is no economy without its critical services, including clean and abundant water, clean air and food. Nature across most of the globe has now been significantly altered by multiple human drivers, such as land-use change, pollution, extraction of minerals, abstraction of water and climate change. Statistics on the current state of biodiversity loss and environmental degradation are alarming: the extent and condition of ecosystems has declined in 50% of natural ecosystems, including more than 85% of wetland area lost, and 25% of species are at risk of extinction (IPBES, 2019). The 2019 Global Assessment Report of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) concluded that fourteen of the eighteen ecosystem services that were assessed had declined since the 1970s. The United Kingdom is no exception. The percentage of UK habitats 'in favourable or improving conservation status' has been deteriorating since 2007, exacerbating impacts on our soils, pollinators, air and environmental pollution, water and flood protection. Our analyses show that 75% of the United Kingdom is covered by at least one hotspot of natural capital depletion, and 25% is covered by two or more hotspots of natural capital depletion. The UK, with its globally interconnected economy, is also exposed to significant global emerging risks.

The erosion of UK and global natural capital generates significant and long-term risks to society and the UK economy and financial sector. Studies by Central Banks around the world have highlighted the high degree of dependence on nature and the exposure of financial portfolios to nature-related risks. What is not yet clear, is the extent to which this is a material risk to financial stability, on a par with other risks on the radar of Central Banks, and if so, on what timescales this risk could emerge and where it might 'fall through the cracks' of current supervision and regulation.

The objective of this project was to assess the materiality of nature-related risks to the UK financial sector both in the near-term and the longer-term. To address this, we develop six innovations:

1. The first Nature-Related Risk Inventory for the UK (UK-NRRI), equivalent in format to the National Risk Register or Climate Change Risk Assessment (CCRA).
2. Dependency analysis with spatial information to track dependencies on international supply and the nature risks therein, alongside transition risk exposures for the seven largest banks.
3. Development of sector-specific nature-related Value at Risk (nVaR) scores.
4. Co-development of three benchmark scenarios of nature-related risks, following the approach outlined by the Taskforce on Nature-Related Financial Disclosures (TNFD 2023).
5. Macroeconomic modelling to gauge the potential impacts on UK prosperity and resilience.
6. Preliminary financial 'stress test' for the domestic lending of the UK's seven largest banks.

The analyses focus on physical nature-related risks, with exposure analysis or transition risks.

The findings demonstrate that biodiversity loss and environmental degradation create material risks for the UK economy and financial sector, in addition to their wider social and biodiversity impacts. These impacts are near and present. We find that the deterioration of our natural environment could slow economic growth and result in UK Gross Domestic Product (GDP) being 6% lower than it would have been otherwise by the 2030s under two scenarios (domestic and international) and 12% lower under an AMR-pandemic scenario. These are greater than the impact on GDP experienced in the Global Financial Crisis, in which UK GDP fell by around 4% to 6%, and - for the AMR-pandemic scenario – greater than the GDP impact of the COVID-19 pandemic when GDP fell 11% over 2020. While these findings are preliminary, all the evidence points to them being conservative. This study focussed on quantifying near- to medium-term risks, but the evidence clearly demonstrates these risks will increase over time with the potential for crossing tipping points.

The compounding impacts of climate and nature loss would have a very material impact on UK GDP; equivalent to several lost years of growth. It is not realistic to consider nature in isolation as climate change and environmental degradation are occurring in parallel and are interconnected. Environmental degradation increases the likelihood and severity of an acute climate or health shock, and the combined effect would have a very material impact on the economy. For this reason, we also draw upon the NGFS climate scenarios to explore the compounding impacts of climate and nature. We find that in our acute shock scenarios, these compounding impacts can lead to a UK GDP that is 8% lower than it would be otherwise, with a peak shock that wipes out around £200 billion from UK GDP and persists for several quarters, equivalent to 4 – 7 years of lost growth over the period.

he gradual impacts of environmental degradation on the economy are as detrimental or more so than climate change in the near-term - and the chronic year-to-year changes lead to losses that are as important as more sudden shocks. We find that the impact to GDP of chronic year-on-year environmental degradation is at least on par with that from physical climate change risks in the coming decade and for acute shocks, can be far greater than climate impacts alone. In effect, the impacts of environmental degradation are doubling or more the impact of climate change. Antimicrobial resistance (AMR) and zoonotic diseases are closely linked with deforestation and habitat destruction which can bring humans and wild animals into closer contact and have been shown to lead to greater abundance of antibiotic resistance genes in soil. Chronic nature-related risks associated with soil degradation, water provisioning, pollution and pollination services have material impacts on agriculture, manufacturing, construction, utilities and key supply chains.

Around half of UK nature-related risks come from overseas, through supply chains and financial exposures, pointing toward the importance of working internationally to close the gaps in disclosures and risk management. The four trillion GBP of financial assets assessed are dependent upon many trillions more of assets globally. Analyses of UK financial exposures suggest that 56% of the total upstream financial exposures have a High or Very High dependence on ecosystem services. Exposures to overseas risks are most material (in financial terms) for the services and manufacturing sectors, with highest risks related to water.

The agricultural sector is most at risk in percentage terms, but the largest risks in monetary terms are to the services and manufacturing sectors. Agriculture can be impacted by disruption to several ecosystem services, with potential reductions in output (the nature-related value at risk – or nVaR) up to 15% of total annual production for disruption of any one service, albeit multiple ecosystem services at risk and impacts occur simultaneously, with risks to related to pollination services, soil quality and invasive species. Looking across the UK economy, we find that the nVaR associated with disruption to ecosystem services is in the hundreds of billions and equivalent to several percentage points of GDP; water risks alone are equivalent to around 13% UK GDP (for an extreme 1-in-100 year risk). The agricultural sector is also the most exposed to transition risks and opportunities.

Looking across the portfolios of the seven largest UK banks, the analyses indicate possible adjustments in the valuations of domestic holdings (excluding finance) of up to 4 – 5% over the coming decade from physical nature-related risks. Depending on the bank, the most at-risk sectors include agriculture, utilities, real-estate and manufacturing. Preliminary analyses suggest that between 8% and 53% of the portfolios of the seven largest banks are exposed also to transition risks. Firms could also derive opportunities from the nature-positive transition; including new demand for nature-positive products and services.

The findings of this study take us further than previous studies to-date by clearly demonstrating the materiality of nature-related risks and the potential for compounding risks with climate change. Further work is needed to assess the implications for regulation, policy and supervision.

Based upon the findings presented here and elsewhere, we believe there is a case for action by Central Banks, regulators and governments to assess if and where nature may be falling through the cracks of current frameworks and where this could lead to financial stability risks that justify explicit changes to those frameworks. We make a series of arguments based on the evidence for why nature may present new challenges that necessitate action. It is clear, for example, from other work (e.g. GARP 2024 and TNFD 2023), that there are sizeable information asymmetries created by the lack of disclosures of nature-related risks and impacts that mean that risks are currently under-priced. This may lead to an accumulation of systemic risk that goes undetected. We also lay out how nature-related risks suffer from the same 'tragedy of the horizon' issue identified by Mark Carney in 2015, but also additional challenges of a 'tragedy of scale' and unique drivers and risk transmission channels that are not captured within current climate-related risk assessments.

This study adds further evidence to support the conclusion from the Dasgupta Review and others that an early orderly transition toward a nature-positive economy brings significant benefits for UK prosperity and financial stability, through reducing both transition and physical risks, as well as for people and planet. Actions that could be considered by regulators and supervisors to mitigate risks to financial stability include advancing disclosures, broadening supervisory statements on climate to explicitly include environmental risks and introducing a simple nature-risk scenario within exploratory scenario exercises. There are many low-regrets measures that could be taken now, including supporting capability building through fora such as the Climate Financial Risk Forum and working with the scientific community to advance a set of benchmark scenarios, building upon those developed here. Regulators should also take timely opportunities to incorporate nature alongside climate into emerging frameworks, for example on transition plans, ISSB standards and taxonomies.

For financial institutions, the findings should motivate action to assess and manage nature-related financial risks, build capability, and begin to incorporate nature into emerging transition plans. These preliminary results suggest that even in the short-term nature-related risk is not negligible, especially if the losses are considered in relative terms to specific fractions of a lending portfolio. Financial institutions can manage risks to their own portfolios through working with their clients to reduce risks through supporting their transition and resilience. Importantly the transition toward a nature-positive economy presents opportunities as well as risks. With early action, UK firms – both financial and real-economy – can capture these opportunities.

For government, the materiality of nature-related risks demonstrated in this study add additional urgency to put in place the mechanisms, domestically and globally, to meet the goals and targets of the Kunming-Montreal Global Biodiversity Framework (GBF), as well as domestic policies such as the Environmental Improvement Plan (2023). This includes engaging internationally to ensure that emerging sustainable finance frameworks incorporate nature and nature related, including the IFRS Foundation's ISSB. There is also an urgent rationale for investment and closer working with the scientific community to improve data and analytics as a public good to underpin the UK's transition to a resilient, nature-positive economy.

To continue to advance this area, strengthening collaboration between financial institutions and the scientific community is essential. Nature-related financial risk assessment is in its infancy, but risks are significant. This study has revealed several gaps in knowledge and approaches that require further study. It has also produced a series of tools that can be advanced today:

- **A Nature-Related Risk Inventory (UK-NRRI)** that includes 29 key risks to the UK, with zoonotic diseases and antimicrobial resistance, soil health decline and global repercussions of food insecurity emerging as highest risks in terms of likelihood and impacts.
- **A set of benchmark narrative and quantitative scenarios** that could form the basis for the further co-development of a set of scenarios for financial institutions, through fora such as the Climate Financial Risk Forum and UK Integrating Finance and Biodiversity network.

There is a need to build platforms for collaboration and an opportunity to build upon existing fora such as the Climate Financial Risk Forum. The new £7m UKRI Integrating Finance and Biodiversity network, bringing together 17 research institutions, provides a ready venue to deepen collaborations.

Finally, while our focus has been on nature-related risks, the findings have implications for climate change given the strong interconnections between climate and nature The findings suggest that incorporating nature-related risk amplifications in climate scenarios would double the estimated impact of climate change on the UK economy, beyond what is currently predicted by the NGFS.

Contents

Definitions

All definitions used in this report are consistent with those defined by the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES), the equivalent of the Intergovernmental Panel on Climate Change, IPCC). In most cases, these are consistent with those used by the Taskforce on Nature-Related Financial Disclosure (TNFD 2023).

Nature is defined as "the natural world with an emphasis on its living organisms" and includes biodiversity, ecosystems and the biosphere. This definition is used whilst acknowledging that it "embodies different concepts for different people" (IPBES, 2019, p. xiv).

Biodiversity is defined as the "variability among living organisms from all sources including, inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems." (CBD, 1992).

Ecosystem services "The benefits (and occasionally disbenefits or losses) that people obtain from ecosystems. These include provisioning services such as food and water supply; regulating services such as flood and disease control; and cultural services such as recreation, ethical and spiritual, educational and sense of place". ENCORE uses 21 ecosystem services drawn from the Common International Classification of Ecosystem Services (CICES version 4.3), whereas IPBES defines eighteen categories of Nature's Contribution to People (NCPs).

Nature's contribution to people (NCP) "are all the contributions, both positive and negative, of living nature (i.e., all organisms, ecosystems, and their associated ecological and evolutionary processes) to people's quality of life." (IPBES, 2019, p. 1046).

Natural capital "A concept referring to the stock of renewable and non-renewable natural resources (plants, animals, air, water, soils, minerals) that combine to yield a flow of benefits to people". Within the IPBES conceptual framework, it is part of the nature category, representing an economic-utilitarian perspective on nature, specifically those aspects of nature that people use (or anticipate to use) as source of Nature's contributions to people" (IPBES, 2019).

Nature-related financial risks (NGFS, 2022) "risks of negative effects on economies, financial institutions and financial systems that result from: i. the degradation of nature, including its biodiversity, and the loss of ecosystem services that flow from it (i.e., physical risks); or ii. the misalignment of economic actors with actions aimed at protecting, restoring, and/or reducing negative impacts on nature (i.e., transition risks)".

Source: IPBES Glossary (unless otherwise stated)

Introduction

"Given the macroeconomic, macroprudential and micro prudential materiality of nature-related financial risks, such risks should be adequately considered for the fulfilment of their mandates" (NGFS, 2022).

An economy and financial system embedded within and dependent upon nature

The dependence of our economies on nature and natural capital is fast rising up the agenda of Central Banks and supervisors and is now fully embedded within the wider discourse on potential exogenous threats to financial stability. Previous studies by Central Banks around the world have highlighted the high degree of dependence and the exposure of financial portfolios to nature-related risks. What is not yet clear, is the extent to which this is a material risk to financial stability, on a par with other environmental and non-environmental risks on the radar of Central Banks, and if so, on what timescales this could emerge.

To answer these questions and begin to manage these risks, we need to develop new approaches that shift from dependency analysis to risk analysis. The overall objective of this project is to provide a first 'order of scale' estimate of the potential size and materiality of the economic and financial risks associated with biodiversity losses and environmental damage in the UK, accounting for both domestic and transboundary risks. We refer to these collectively in this report as nature-related risks (NRRs) and follow the definition of the Network of Central Banks and Supervisors for Greening the Financial System: "risks of negative effects on economies, financial institutions and financial systems that result from: i. the degradation of nature, including its biodiversity, and the loss of ecosystem services that flow from it (i.e., physical risks); or ii. the misalignment of economic actors with actions aimed at protecting, restoring, and/or reducing negative impacts on nature (i.e., transition risks)" (NGFS, 2023a)[1].

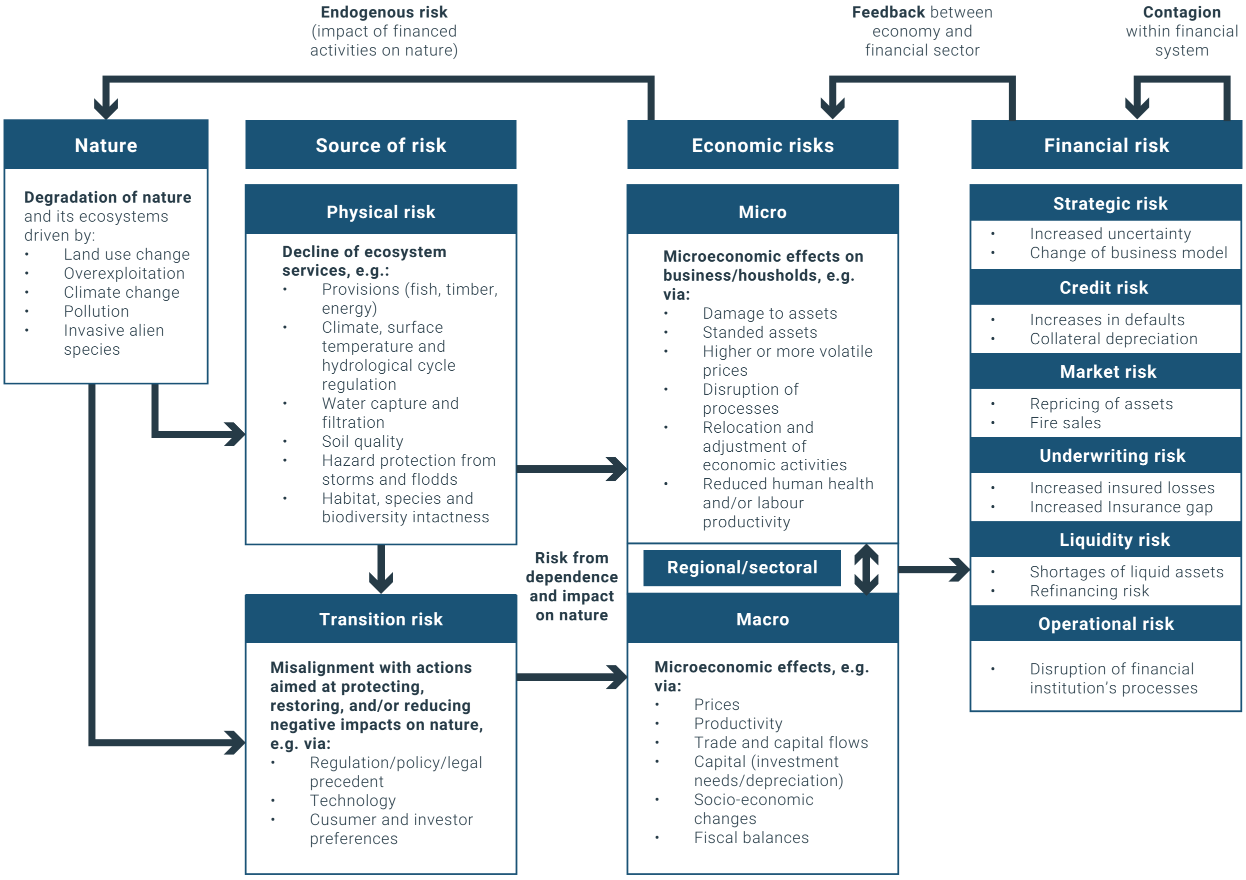


Figure 1: Transmission channels for nature-related risks. Source: NGFS (2023).

[1] Litigation risks can also arise as a result of physical risks; for example, legal action brought against a company alleged to be responsible for causing harm to ecosystems, or as part of transition risks, such as when businesses fail to adapt to new regulations and face legal consequences.

Figure 1 maps the transmission channels from nature to finance, identifying the important role of both regional, sectoral and macro- and micro-channels that – for the first time - we attempt to capture in this project, consistent with the principles and frameworks developed by TNFD.

Greening finance for nature

The need for action globally to protect and restore biodiversity and natural capital is clear and well accepted. Half of global GDP is moderately or highly dependent on nature and its services (WEF, 2020), yet ultimately 100% of the economy is dependent on nature in some respect as it is intrinsic to human life and there is no economy without it (Dasgupta, 2021). Statistics on the current state of biodiversity loss and nature degradation are alarming: the extent and condition of ecosystems has declined in 50% natural ecosystems, including more than 85% of wetland area lost, and an average of 25% species are at risk of extinction (IPBES, 2019). The 2019 Global Assessment Report of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) concluded that fourteen of the eighteen ecosystem services ('categories of Nature's contribution of people') that were assessed had declined since the 1970s. Nature across most of the globe has now been significantly altered by multiple human drivers, including land-use change, pollution, extraction and climate change. The erosion of this natural capital generates significant and long-term risks to society and therefore financial institutions, from increasing the risk and impacts of pandemics, floods and droughts, to undermining water quality and supplies, damaging agricultural production and creating risks to human health. The Kunming-Montreal Global Biodiversity Framework (GBF) – arguably the equivalent of the Paris Agreement for climate change, adopted in 2022 – sets an ambitious pathway toward the global vision of a world living in harmony with nature by 2050, with four goals for 2050 and 23 targets for 2030, including the alignment of finance with the GBF goals.

To meet the goals of the GBF, finance needs to play its part. Activities financed by financial institutions today have a significant and negative impact on nature. For example, UNEP (2023) estimated that finance flowing into activities that degrade nature totals around $5 trillion per year, while it tracked nature-positive finance of the order of only $200 billion a year. These estimates come with uncertainties, but this serves to illustrate the core problem. As outlined by NGFS (2022), financial firms also face significant risks themselves from biodiversity loss and environmental degradation. These risks are not currently priced into financial markets, and this contributes to the continued allocation of finance to activities that create the damage. Greening finance is about ensuring that financial decisions take account of these risks (and impacts), with the goal of redirecting financial flows toward nature-positive activities.

The UK Green Finance Strategy 2023 laid out ambitious plans to both integrate nature into financial decision making and to mobilise increased public and private finance into nature recovery, including setting a goal to mobilise more than £1 billion per year of private finance into nature's recovery in England by 2030 (Annex 1)[2]. This included reasserting that UK's commitment to Target 15 within the Global Biodiversity Framework to ensure the largest companies regularly monitor and disclose their risks, dependencies and impacts on nature.

[2] "https://assets.publishing.service.gov.uk/media/643583fb877741001368d815/mobilising-green-investment-2023-green-finance-strategy.pdf

The case for action by central banks and supervisors

Central Banks and supervisors can play a powerful, but specific and bounded, role in achieving this global vision, aligned with their mandates. The fact that financial institutions do not currently fully account for nature-related risks in their decisions potentially exposes the sector to unmitigated systemic risks - a core concern of Central Banks - as well as contributing to the inefficient allocation of capital that results in finance continuing to flow to activities that damage nature and generate risk. Nature-related risks could also have implications for monetary policy – a further responsibility of Central Banks. However in the context of this project, by design, we are working mainly within the financial stability mandate; that is, macro-prudential and micro-prudential risk management. Nevertheless, our insights may also be relevant to monetary policy as well as to financial institutions assessing nature-related risks.

To date, most action by Central Banks and supervisors on climate change has been justified in terms of managing potential risks to financial stability. It was recognised, for example, that climate change could pose a significant risk to medium-term financial stability, and the fact that financial institutions are not accounting for this risk today due to their shorter-time scale of decision making, means that this risk is not being proactively managed. This is known as the 'Tragedy of the Horizon' (see e.g. Carney (2015): 'Once climate change becomes a defining issue for financial stability, it may already be too late'). Recognition of the Tragedy of the Horizon brought climate risks squarely into the remit of Central Banks and enabled them to begin to deploy their toolkit of interventions to start to encourage (and require) financial institutions to assess, disclose and if necessary, manage climate-related risk. In the UK, the Bank of England and wider financial regulators have taken several measures to ensure the UK financial system is resilient to climate change, including through mandating climate-related disclosures, supervisory expectations, and running the first climate scenario analysis, the 2021 Climate Biennial Exploratory Scenario (CBES). Together, and coupled with the wider market evolution (e.g. the Taskforce on Climate-Related Financial Disclosures and the IFRS standards), these have increased capability and strengthened climate risk management across the sector, albeit technical capabilities in defining scenarios and assessing risks are still nascent (Ranger et al. 2022). Indeed, the erosion of natural capital further amplifies climate risks - and is arguably a major 'missing risk' - that means our current estimates of climate financial risks are too low.

For the case of nature-related risks, Central Banks (and regulators and financial institutions more widely) are arguably where they were around 5 – 10 years ago with climate change risks (Ranger et al. 2023). That is, making the first assessments of the potential risks related to damage of biodiversity and ecosystems for financial stability, in order to take decisions on what additional analyses and measures may be required. Scenario analysis and stress testing is an important tool used by financial institutions and Central Banks and supervisors to do this. Arguably, the challenges of lack of capability and uncertainties in risk are even greater for the case of nature in comparison to climate change, particularly given the challenges in assessing potential future social, economic and financial impacts of nature loss.

Status of progress in assessing nature-related financial risks

Several Central Banks have now begun to assess nature-related financial risks. This includes the Netherlands (van Toor et al., 2020), France (Svartzman et al., 2021), Brazil (Calice et al., 2021), Malaysia (WB & BNM, 2022), Mexico (Martínez-Jaramillo and Montañez-Enríquez, 2021) and for the Euro area (Boldrini et al. 2023). De Nederlandsche Bank (DNB) undertook pioneering work on assessing biodiversity – physical – risks to the Dutch financial sector. Using the ENCORE tool, the analysis estimates that 36% of their portfolio has a high/very high dependency on at least one ecosystem service (ES) (van Toor et al., 2020). The DNB study also focuses on transition and reputational risks. The results in this study provide lower boundary estimates given that neither nature-related systemic risks nor nature-climate-risks interactions are included. Banque de France (BdF) analysis builds on DNB's work by estimating upstream dependencies using the EXIOBASE3 input-output table. In line with results from DNB, surface water and groundwater are the ESs with higher dependencies. The Bank Negara Malaysia analysis follows a similar approach to that used by DNB but also includes exploratory nature-related physical and transition risk scenarios for Malaysia. These were developed based on the ES dependencies/ impacts results using ENCORE and stakeholder interviews (BNM & WB, 2022). Most recently the European Central Bank (ECB) took a similar approach on dependencies analysis (Boldrini et al. 2023) and impact analysis (Ceglar et al., 2023). A drawback of these pioneering studies is that they focus on dependencies of the economy on nature, but as yet provide only limited insight on the materiality of the financial risk to firms.

Building on DNB and BdF's work, the report by Vivid Economics and FSD Africa (2022)[3] quantifies the opportunities and risks for financial institutions in Africa under a range of climate and nature scenarios up to 2050. It presents results of the first stress test on nature-risk for financial institutions, moving beyond dependencies to risk, by applying the first three stages of the TNFD's LEAP[4] approach. A recent report presented the first "integrated nature and climate scenario for use by investors" (IPR, 2023, page 4). This new FPS+nature scenario builds on an existing climate transition scenario - Forecast Policy Scenario (FPS) - which was developed from plausible policy trajectories. The FPS+nature scenario focuses on transition risk up to 2050. It does not account for acute physical risk, which is the main focus of this project[5]. There are several other notable studies that have partially quantified nature-related risks for particular sectors or ecosystem services (see Ranger et al. 2023 for review).

The nature of nature-related financial risks and implications for risk assessment

A challenge of the majority of existing studies is that they do not capture the range or scope of potential nature-related risks and therefore, the risk assessments are very conservative. Of particular importance is the potential for complex, cascading and compounding shocks; also identified as a key missing element of climate scenario analyses (e.g. NGFS 2023b).

Our nature-climate-economy system is complex, and it is well known that complex systems behave non-linearly, with unexpected outcomes and thresholds that can amplify shocks and lead to quasi-irreversible effects locally. Ranger et al. (2023) describe, for example, how soil salination due to clearing land for agriculture can erode soil quality until a threshold is breached, whereupon agricultural productivity can collapse. In Western Australia the lost agricultural productivity from salinity damage is estimated to be worth at least $519 million per year (Government of Western Australia, 2022). The negative impacts of environmental change in one country can transmit globally through natural systems (water systems, climate) and human systems affecting people and economic output in other countries via global supply chains and trade. The interconnectedness of systems globally establishes pathways for the transmission of risks through trade, finance, food and ecosystems, exacerbating existing stressors and constraining adaptation, generating larger and more complex risks to agriculture, water, health, people and economies (Pörtner et al. 2022). At least three of the nine major climate tipping points identified in Lenton et al. (2019) are directly linked with systems under threat through biodiversity loss and environmental degradation (the Amazon rainforest, coral reefs and Boreal forests), suggesting the potential for nature-related risks to accelerate rapid changes in global climate or heighten the impacts and so cause severe and potentially irreversible social and economic impacts.

[3] This study was not specifically developed for Central Banks but given the limited literature it was included here
[4] Locate, Evaluate, Assess, Prepare
[5] "modelled chronic physical risks include changes in average temperature and average precipitation rates, both of which impact crop yields; modelling does not account for nature-related chronic physical risks, such as loss of pollination." (IPR, 2023, page 33)

Characteristics	Climate-related physical financial risks	Nature-related physical financial risks
Driver	Global, Increasing GHG emissions and changes in natural sinks directly attributable to human activities	Local (albeit could occur as a global trend). Wide range of drivers directly attributable to human activities
Acute and chronic	Both acute (shocks) and chronic (gradual) impacts	Both acute (shocks) and chronic (gradual) impacts
Diversity of impacts	Wide range of potential impacts on natural and human systems	Range of potential impacts on natural and human systems is arguably even wider and more direct than for climate change, including changes in genetic materials for medicines etc.
Timescales	Immediate but time delay before the physical impacts of GHG emissions fully manifest	Impacts of nature degradation can be immediate or can build up over time
Spatial scales and localisation	The impacts of rising GHG concentrations are global, albeit are spatially heterogenous and determined by a combination of local nature and socioeconomic factors (including nature loss)	Impacts of nature degradation are local, and determined by local natural and socioeconomic factors, however can also have a global impact, due to connections across natural and social systems
Linearity, uncertainty and predictability	The relationship between climate change and local and global physical climate risks can be strongly non-linear, with potential for compounding and cascading risks that can amplify local effects, making prediction difficult	The relationship between nature and related local and global physical nature risks can be strongly non-linear, with potential for compounding and cascading risks that can amplify local effects, making prediction difficult
Thresholds and tipping points	Climate change can drive tipping points in nature and socioeconomic systems with extreme impacts	Nature degradation can drive tipping points in natural and socioeconomic systems with extreme impacts
Climate-Nature Risk amplifiers	Nature degradation and associated socioeconomic vulnerabilities are risk amplifiers of climate risks	Climate change, natural climate variability and socioeconomic vulnerabilities are risk amplifiers of nature risks
Status of modelling	Integrated assessment models for climate are well known to capture only a fraction of potential physical climate risks. Models include many sources of uncertainty and collaborative efforts such as ISIMIP play an important role in helping to ensure model comparability.	Integrated assessment models for nature are at a nascent stage, capturing only certain processes and so likely underplay the risks. Projections that exist are uncertain. Model comparability is challenging due to lack of structured comparison efforts analogous to ISIMIP.

Table 1: Climate versus nature-related financial risks. Adapted from Ranger et al. (2023)

Of course, physical climate risks also share these characteristics (Table 1). However, as outlined by Ranger et al. (2023) there are also important differences to nature risks and this has implications for risk assessment that are reflected in the methodologies developed for this project. This includes the strong localisation of drivers and risks in nature and the immediacy of potential risks. Nature risks are highly specific to individual countries and local communities, driven by a large and diverse number of interrelated and interacting factors that are unique to the local ecological, social and economic context, so these issues pose challenges for financial risk assessment. Given this evidence, the 2023 NGFS Occasional Paper (Ranger et al. 2023), proposed a set of principles for nature-related risk assessment and scenario analysis that are adopted here.

Another important difference between nature and climate risks is that the status of modelling is less developed for nature. Despite the imminent and substantial threats to nature and its services, approaches to quantify the potential financial and economic impacts of nature loss, and to model and project future impacts under different scenarios of socioeconomic change, is arguably less advanced than for climate change; which itself retains many knowledge gaps and uncertainties. For example, there has never been a coordinated effort to compare and assess models, analogous to the Coupled Model Intercomparison Project (CMIP) that underpins the projections of the Intergovernmental Panel on Climate Change. This means that such projections come with uncertainties and need to be interpreted accordingly. Models inevitably reduce the complexity through for example, only representing certain drivers, sectors or transmission channels, yet this can mean that important feedbacks are excluded (see model review in NGFS 2023a). These issues are amplified when one begins to model the economic and financial implications, which requires understanding complex processes of price and demand dynamics, substitutability, financial contagion, innovation and behavioural responses across consumers, producers, corporates, trade, investors and governments. In addition, and most importantly, there are large gaps in the availability and accessibility of the data required to develop, calibrate and validate models and also a paucity of empirical evidence. This means that those models that exist, will be prone to underestimate the risks (NGFS 2023a).

Given the complexity and local specificity of nature-related risks, TNFD (2023) and Ranger et al. (2023) recommends a scenario approach that begins with the exploration of narrative scenarios. As noted by Schinko et al. (2017) in the context of deep uncertainty, models and scenarios that allow to "explore rather than predict" can better help understand the drivers of individual and system-level responses to shocks in comparison with forecasting models. To account for these complexities, our methodology includes model-based projections alongside narrative and partially-quantified scenarios developed through expert judgment and the best available science, consistent with the approach recommended by Jack et al. (2020) and Ranger et al. (2023). In this way, it combines the 'narrow and deep' (addressed through quantitative modelling) with the 'broad and shallow' through storylines. This approach is consistent with the standard requirements for financial stress testing and vulnerability assessment (e.g. IMF 2019).

Methodology

The central question of this study is to what extent biodiversity loss and environmental degradation poses a material risk to financial stability, on a par with other environmental and non-environmental risks, including climate change. To answer this question, we must move beyond the dependency analysis completed by Central Banks to date and into full financial risk analysis, as well as address – to the extent possible - the 'missing risks' not captured in previous studies. Our approach to doing this is grounded in the science but takes a financial perspective; focussing on those risks most likely to lead to material financial impacts. Our focus in this first analysis is on physical nature-related risks. For the UK, further work is needed on transition risks given the need to fully assess the potential significant opportunities that could arise from a nature-positive transition. Accordingly, this project has six innovations:

1. **The Nature-Related Risk Inventory (UK-NRRI):** to inform scenario development, we begin with a broad risk identification exercise, including exploring non-financial (e.g. labour productivity) and second-order effects (e.g. public expenditure impacts and their consequences for inflation) and explicitly aiming capturing the potential for more complex, cascading and compounding risks. The outcome is the development of the first Nature-Related Risk Inventory (UK-NRRI), equivalent in style to the National Risk Register or Climate Change Risk Assessment (CCRA), through consultations grounded in the literature.

2. **Dependency analyses incorporating supply chains and overlaying risk hotspots.** The ENCORE database is combined with a multi-regional input-out (MRIO) analysis to assess indirect supply-chain risks using EXIOBASE and overlaid with ecological information on the state of ecosystem services globally to provide information on exposures to risk. We also qualitatively assess exposures to transition risks using the WWF Biodiversity Risk Filter, using financial data for the seven largest banks gathered from Pillar 3 reports.

3. **Sectoral nature-related value at risk modelling (nVaR):** We introduce a new method for quantitative screening and assessment of nature-related risks to the UK, incorporating an MRIO approach as a proxy to capture indirect supply chain risks and information on the geographical exposures of seven banks overseas from Pillar 3 reports. The output is a 'nature-related value at risk' (nVaR) metric, defined in terms of potential sectoral production loss, analogous to the value at risk metrics commonly used by financial institutions.

4. **Scenario development; from storylines to quantitative scenarios:** Three scenarios of whole-economy physical nature-related risks to the UK are co-developed with financial institutions, consistent with TNFD (2023). The scenarios aim to stress test financial resilience to three different dimensions of risks: domestic, international and health. Given the lessons learnt from climate scenario analysis (e.g. Ranger et al. 2022), and the limitations of integrated assessment models (e.g. NGFS 2023a), our approach begins with defining narrative storylines, which are then specified through a combination of quantitative modelling and expert judgement, including drawing upon historical analogues.

5. **Macroeconomic modelling using NiGEM:** The macroeconomic implications of the nature-related physical risk scenarios are explored through the NiGEM general equilibrium model. NiGEM is used as this is the model utilised by the NGFS for the climate scenarios and so nature and climate risks can be compared and combined. Outputs include Gross Domestic Product (GDP) but also inflation, employment and other macroeconomic variables.

6. **Financial risk assessment:** Assessment of the impacts of the nature-related risk scenarios on the loan portfolios of seven of the UK's largest banks, adapting the methodology developed for climate-related risks by Battiston et al. (2023)[6].

The methodologies for each component are given in their respective Chapters, with additional technical information in the Annexes and additional Supplementary Materials. The flow of the analysis through each of these components is illustrated in Figure 2. The numbers refer to both the innovations above and the relevant Chapter numbers in this report.

The quantitative analysis is divided into two main parts. **Part A** (points 2 and 3 above) uses a risk-based approach to assess value at risk for specific sectors. This analysis is not contingent on any specific scenario but instead represents the probability of a given level of loss. **Part B** (points 4 to 6) take a scenario-based approach, generating estimates of losses contingent on a specific set of events that are defined through the narrative scenarios. Through its narrative approach and use of the macroeconomic model, this part attempts to include second-order effects, such as changes in labour productivity, prices, trade, investment risk premia and public expenditures, alongside the sector-specific impacts.

[6] Note this analysis is based only on sector-specific impacts and does not account for second-order effects

Nature and climate change are intimately linked and this is reflected in the methodologies developed and adopted in this study. While our focus is on those new and additional risks related to nature not captured in existing analyses, it is impossible (and not advisable) to fully decouple nature and climate in financial risk assessment. Climate change is a risk multiplier on the impacts of the erosion of natural capital and vice versa (Ranger et al. 2023). For this reason, our scenario approach fully incorporates climate-related risks and we present the first analyses of the compounding financial impacts of climate and nature. While the analysis is specific to the UK, the modular methodologies are designed to the replicable for any country.

Overview of the Building Blocks within the Overall Analysis

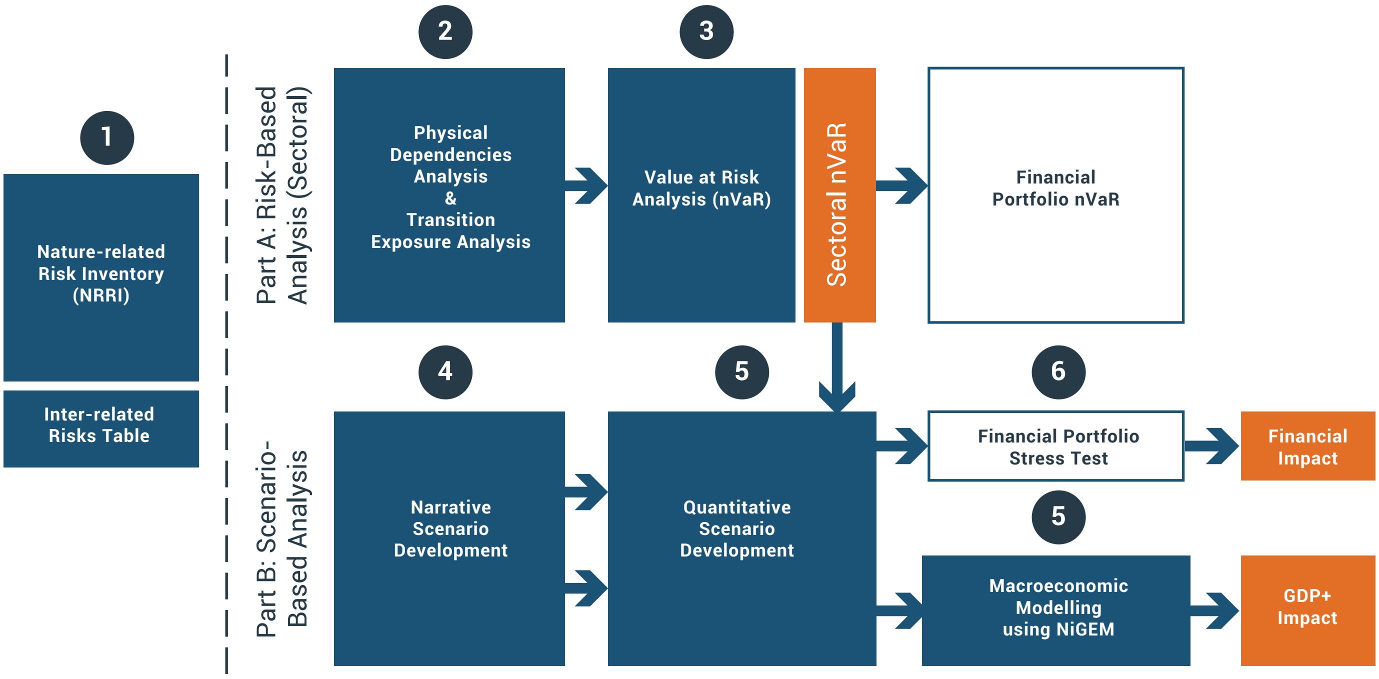


Figure 2: Flow of methodological components of the project.

The outputs of the analysis include both risk-based and scenario-based estimates:

- **Sector-specific nature-related value at risk (nVaR).** This represents the probable loss to sector production at a national-scale. It is expressed both in terms of direct risks and indirect (supply chain) risks. Unless otherwise stated, the risk-based estimates are defined in terms of the 0.99% Value at Risk (i.e. a 1 in 100 year event), consistent with common approaches of financial institutions. Chapter 3 also provides preliminary estimates of nVaR for specific bank portfolios.
- **Financial risk to seven UK bank portfolios,** defined for specific scenarios and in terms of reductions in value of assets. This preliminary analysis focusses on the domestic holdings of banks only and takes as an input the sector nVaR scores.
- **Impacts of scenarios on macroeconomic variables over time,** including GDP.

This project has generated many innovations, however there are limitations and areas for further work, as discussed in the final Chapter. Note that this preliminary project has included the impacts of financial institutions on nature. Assessing impacts and aligning finance with GBF goals will be a topic of Phase II.

Chapter 1. UK nature-related risk inventory

Authors: Tom Oliver, Helen Killick, Jimena Alvarez, Nicola Ranger, Anne Verhoef, Mike Perring

In this report, we present the first extensive Nature-related Risk Inventory (NRRI) for the UK, which details 22 physical risks, five transition risks and two types of litigation risk that arise from the ongoing damage to natural ecosystems (see Supplementary Materials for details).

The NRRI is complementary to analyses such as the UK National Security Risk Assessment (NSRA) and the UK Climate Change Risk Assessment (CCRA) in that it also considers chronic, long-term risks as well as acute event-driven risks, and focuses specifically on risks arising from nature degradation.

Its intended use is to play an important role within decision-making for a wide range of stakeholders by identifying risks derived from nature degradation and the erosion of ecosystem services, thereby enhancing understanding and informing responses. It could help inform policy makers to develop regulation and define public spending priorities, private companies to prioritise risks for further assessment and management, and central banks to consider potential risks to financial stability. In this way, an inventory can prevent unanticipated negative impacts on citizens, businesses, and UK security and prosperity.

It can also support corporates and financial institutions to: i) prioritise specific risks to particular asset types, in order to assess exposure, vulnerability and mitigation options, and ii) develop scenario-based analysis of nature-related risks by understanding which risks are most material to their operations and portfolios, and how these might interact.

The UK-NRRI captures not only economic risks resulting from nature degradation and the erosion of ecosystem services in the UK, but also economic risks to the UK derived from nature degradation and the erosion of ecosystem services beyond UK borders. It captures both chronic and acute risks and their direct and indirect effects. In addition to these physical risks, it also captures transition risks, such as an acceleration of the stringency of nature protection policies, and litigation risks, such as legal cases filed against businesses or governments. The Inventory ranks all these risks based on their likelihood, and the impact they would have on the economy.

This Chapter provides a brief summary of the evidence on the state of natural capital and the related risks in the UK and then introduces the preliminary UK-NRRI. Significant additional data and analyses on each risk area are included in the Supplementary Material 1.

1.1. The state of natural capital in the UK

This section details recent trends in natural capital in the UK which affect the emergence of nature-related risks. A summary follows below with more detailed evidence review available in the Supplementary Materials.

Seventy-five percent of the United Kingdom is covered by at least one hotspot of natural capital depletion, and 25% is covered by two or more hotspots of natural capital depletion[7]. This indicates that the state of natural capital in much of the UK is depleting fast. As such, future provisioning of ecosystem services is at risk. Given that the ONS estimate the total annual value of ecosystem services (limited to only those ecosystem services that they were able to value) in England alone at £35.7 billion in 2020, this fast rate of depletion of natural capital should be a cause for concern (ONS, 2023a). Without keeping natural capital assets intact, it is not possible to rely on the ecosystem services that these assets currently provide.

[7] This can be further explored in an interactive map available at: https://encore.naturalcapital.finance/en/map?view=hotspots

Climate change and environmental degradation act as risk amplifiers; a large proportion of UK nature-related risks are worsened under climate change and the IPCC sixth assessment report evidences rapid observed and projected global heating with systemic socioeconomic impacts (IPCC 2022).

The deterioration in the percentage of UK habitats of European importance in favourable or improving conservation status has significant implications in particular for agriculture and forestry (JNCC Indicator C3a,2023). In 2019, only 8% of UK habitats listed in Annex I of the EU Habitats Directive were in favourable conservation status. Similarly, the percentage of UK species of European importance has also been deteriorating since 2007 (JNCC Indicator C3b,2023). These trends in priority habitats' status and species are also accompanied by a lack of improvement in the biodiversity in the wider countryside, as shown by insect (JNCC Indicator C6 ,2023) and farmland bird indicators (JNCC Indicator C5,2023). These trends increase risks related to control of crop and forestry pests/pathogens and soil health decline. Damage to soils and land use changes also mediate risks from flooding and wildfire risks. Pollination for crops and horticulture is also threatened, as trends in numbers of pollinating insects in the UK are deteriorating. There has been an overall decrease in pollinator occupancy from 1987 onwards, with the UK indicator showing a decrease of 24% in 2022 compared to its value in 1980 (JNCC Indicator D1c, 2023).

The poor ecological status of many of the UK's freshwater systems has implications for human health but also fisheries and water quality. Terrestrial impacts also cascade to freshwater habitat declines. The proportion of surface water bodies (including rivers, canals, estuaries, coastal and lakes) in good or high ecological status in 2020 was 16%, 64% and 39% in England, Wales and Scotland respectively, with trends relatively stable since 2009 (JNCC Indicator B7, 2023). This directly drives risks related to algal blooms in water ecosystems, and exacerbates freshwater pollution. The leaching of antimicrobial resistance genes from farmland into water ecosystems also exacerbates this and creates potentially significant health risks. Despite progress in reducing pollution incidents and background levels of some pollutants (e.g. phosphates), levels of pollutants in freshwaters are already above safe recommended thresholds (EA 2023; EA 2018a; EA 2018b). Raw sewage discharge from sewage networks, in particular storm overflows, but also during normal discharge increases health risks from coliform bacteria impacting recreational water use (DHSC, 2022). Emerging contaminants, such as microplastics and various chemicals, have also garnered heightened attention due to their discernible impact on the aquatic ecosystem. These contaminants stem from routine human activities, ranging from vehicular emissions to laundry practices (DEFRA, 2023b).

Over abstraction of water could combine with climate change, population growth and pollution issues to increase the costs of public water supplies with potential risks arising in circumstances of extreme droughts. The UK relies on a comprehensive water supply system to meet the demands of its population and industries and efforts are well underway to adapt the system to climate change (OFWAT, 2023; UK National Adaptation Programme 3, 2024). Approximately two-thirds of the UK's water supply for public use comes from surface water sources, such as reservoirs and rivers. Manufacturing, agriculture, and power generation collectively consume approximately 25% of water. In the past 20 years the abstractions rose due to demand for electricity generation; in England, around 20% of electricity production relies on freshwater-cooled power stations. The Office for National Statistics (ONS, 2023) estimated the value of their equivalent 'water abstraction' ecosystem service to the UK at £5.4 billion in 2021 prices. Increasing pressure on water provisioning is already being seen in the UK. A third of river catchments in England are currently at risk due to high abstraction levels and demand is expected to rise in the UK without action due to population growth. These trends make the UK more susceptible to the rising risks to water supplies due to drought and climate change. The National Infrastructure Commission (2018) estimated that a severe drought, occurring with a 1% annual probability by 2050, could affect water supply to 40% of households in England. Research for the third Climate Change Risk Assessment report concluded that by mid-century, under central population projection growth and no additional demand-side adaptation, the UK could face a water deficit of between around 650 and 920 Ml/d; this is a relatively small fraction of total current usage

(17,000 Ml/d; HR Wallingford 2020). The Environment Agency projects that, by 2050, some rivers could have between 50 and 80 percent less water during the summer (Environment Agency 2021). Experience of recent years highlights the UK's susceptibility to drought, with economic impacts on energy and agriculture in particular. The Environment Agency (2021) highlights overuse of water already across several catchments in central/SE England and high water stress. Averting stresses in water systems, if ecosystem services are lost, will not only cost the government and associated agencies, but also the many businesses that depend upon water to function.

Changes in land-use can also increase flood risk in the UK. Fitch et al. (2022) estimate that, in the absence of vegetation providing flood protection ecosystem services in the UK, 'an extra 8.5 billion m3 (10-year average) of water would have travelled downstream into flood risk zones each year'. By their calculations, flood protection from vegetation provides annualized value of £4 billion per year (2021 prices) to the UK.

UK marine ecosystems are also under threat, including by invasive species and climate change. In 2020, 56% of UK quota-fish stocks were fished sustainably, at or below acceptable mortality range levels (this has increased from 11% in 1990), while 21% still remain fished at unsustainable levels, with the remainder unknown (JNCC indicator B2, 2023). Of the 'top 10' stocks on which the UK fishing industry relies, half are overfished or their stock size is at a critically low level (Oceana, 2023). There is clear evidence that, largely as a result of climate change, warming seas, reduced oxygen, ocean acidification, nutrient pollution and sea-level rise are already affecting UK coasts and seas. Increasingly, these changes are having an impact on food webs, with effects seen in seabed-dwelling species, as well as plankton, fish, birds and mammals (MCCIP, 2020). Marine invasive species pressures are increasing and since 1969, the number of these species established in or along 10% or more of Great Britain's land area or coastline has increased in the freshwater, marine (coastal) and terrestrial environments, thereby increasing the likely pressure on native biodiversity (JNCC Indicator B6, 2023). These trends suggest increases to risks related to North sea fisheries, ocean acidification and aquaculture pests.

Loss of biodiversity also has important implications for people, including health, tourism, recreation and labour. Biodiversity has been demonstrated to improve mental wellbeing, by reducing stress, improving cognitive function, increasing social cohesion and fostering imagination and creativity, particularly in children (Cianconi et al. 2023). International Access and the quality of the natural environment are important for mental health (PHE 2020a) but clearly a whole range of other socio-economic factors influence this risk. Declines in the quality of the UK environment might also be expected to adversely affect risks related to tourism, though many other additional factors also influence this risk.

But the UK is also exposed to risks related to biodiversity loss and environmental degradation overseas, in particular through its trade, supply chains and position as a global financial centre. 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). 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). For most products, supply chains are complex and thereby prone propagators for risks transnationally. Disruptions in food production, for instance, are also often interacting with related factors, such as biofuel policies boosting grain-use for fuel or export bans, amplifying supply chain disruptions and creating food price spikes such as those in 2007/8 and 2010/2011. China remains UK's second largest trade partner for imports (after the US). Figure 1.1 shows "UK imports of goods from markets with limited sources of supply", with highest concentration in China given its leading role in exports. This figure highlights the already existing limitations around UK access to goods, which may be jeopardised further by nature and climate induced disruptions in different parts of the supply chains. Supply chain dependencies and risks will be modelled in Chapters 2 and 3 using a multi-regional input-output model.

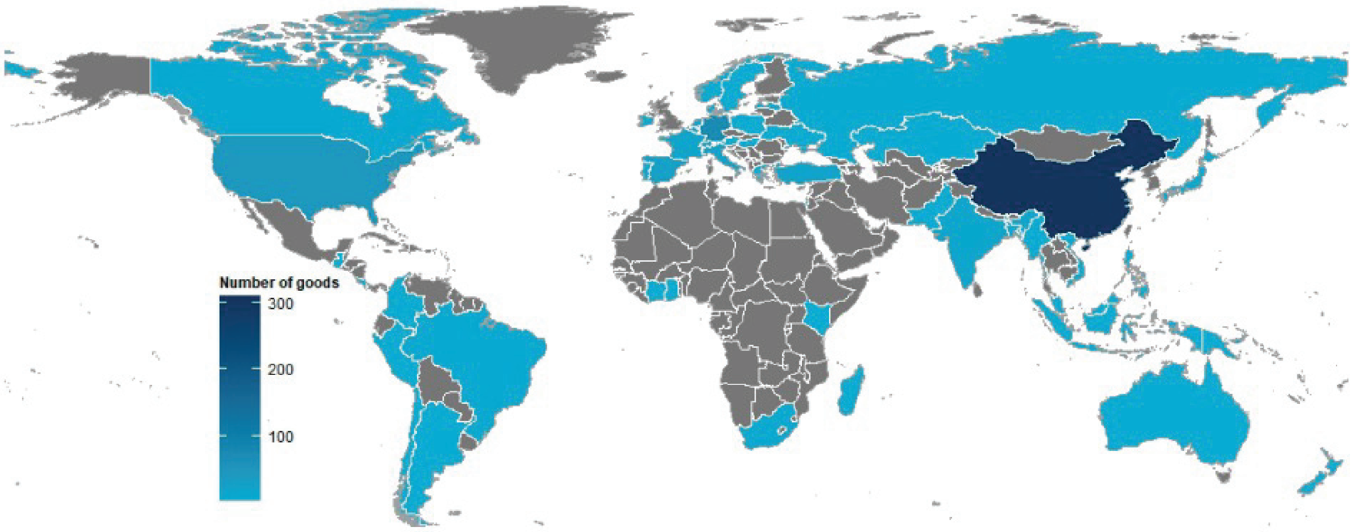


Figure 1.1: Map of UK vulnerable goods imports (2021 trade data).
Source: HMG Critical Imports and Supply Chains Strategy 2024

The high level of interconnectedness of our economy and financial system globally increases the change of complex, cascading risks associated with environmental degradation. Looking across the world, 101 countries have >75% of their land area covered by one or more hotspots of natural capital depletion, and 100 countries have >25% of their land area covered by 2 or more hotspots of depletion. This poses significant risks across multiple global systems, from food to financial services and critical supply chains required for manufacturing. "A negative and compounding feedback loop is likely, involving shifting weather patterns and ecosystems, increased pests and diseases, heatwaves and drought, driving unprecedented food insecurity and migration – all with far reaching consequences." (Chatham House, 2021)

For example, studies suggest an increasing risk of simultaneous failure of wheat, maize and soybean crops, and worsening risks under faster global heating scenarios and this could be aggravated through soil erosion, invasive species and other risks associated with biodiversity loss (Gaupp et al, 2019; Gaupp et al, 2020, McKinsey, 2020). Literature points to evidence of rising risks of 'Multi-breadbasket failure' MBBF from a combination of changes in land-use and water cycles linked with human-induced changes and climate change. Recent analysis demonstrates that climate and crop model projections consistently underestimate the likelihood of extreme weather events that could trigger MBBF (Kornhuber et al. 2023). Risks of climatic extremes leading to global breadbasket failure vary according to type of crop – increasing risk of simultaneous failure of wheat, maize and soybean, but decreasing risk for rice (Gaupp et al. 2020). Such an event would increase the price of food for UK, but could also lead to wide spread impacts such as human migration and civil unrest.

With regards to livestock and human zoonotic diseases such as COVID-19, the Global Health Security Index (2021**) measures the capacities of 195 countries to prepare for epidemics and pandemics and finds "all countries remain dangerously unprepared for future epidemic and pandemic threats, including threats potentially more devastating than COVID-19".** The development of antimicrobial resistance (AMR) is significantly influenced by the overuse and misuse of antimicrobial medicines in healthcare, agriculture, and animal husbandry (O'Neill, 2016). Additionally, environmental pollution with antimicrobials is further escalating the emergence and spread of resistant microorganisms and AMR genetic elements. Antimicrobials find their way into the environment through various channels, including insufficient degradation in wastewater treatment, sewage overflows, direct disposal of human and animal waste, as well as discharges from hospitals, pharmaceutical manufacturing, and agricultural practices (Singer et al., 2016; Larsson & Flach, 2021). AMR is a significant threat to humans, animals/livestock, and the environment. In this scenario, bacteria, fungi, viruses and parasites become resistant to antimicrobial medicines that have spread widely in the environment. This includes antibiotics and antifungal agents, causing diseases that are more difficult to treat and potentially easier to spread. AMR can also be associated with a pandemic outbreak in which mortality is more severe than COVID-19 (e.g. double the country level mortality, see JHU Coronavirus Resource Center, 2023). This is still conservative since some strains of avian influenza (e.g. H5N1) have caused a 60% fatality rate in humans (Sah et al. 2023). For livestock, AMR affects animal health, impacting food safety and food security (i.e., disrupting critical supply chains and trade of livestock). Additionally, AMR present in the environment contributes to a reduction in water, soil, and crop quality which again contributes to supply chain interruption. In economic terms, AMR has adverse impacts on a range of sectors. These include changes in labour market dynamics and productivity, challenges in livestock industries, and potential setbacks in the tourism industry due to health concerns.

Rapidly implemented but mis-aligned policy on nature-related risks has the potential to cause transition risks, but could also lead to opportunities for UK firms. The extent of transition risks depends on policy pathways and the alignment of action between the UK and other countries. The inevitable policy response scenarios also outline other potential drivers of transition risks including changing diets and market sentiments toward sustainable products and services.

Both physical nature-related risks and transition risks are highly contingent on environmental policy implementation both nationally and globally. The development of Environment Act targets and indicators began in 2021 and were laid in parliament in December 2022. Following this the government published an Environment Improvement Plan, which lays out the UK government's plan for improving the state of the environment (i.e. for restoring biodiversity, water quality, air quality and biosecurity) (DEFRA, 2023a). The Environmental Improvement Plan, published in January 2023, set out a legally binding target to halt the decline in domestic species abundance in England by 2030, and then increase abundance by at least 10% to exceed 2022 levels by 2042. Adherence to this plan is scrutinised by the Environmental Audit Committee (e.g. UK Parliament, 2022a) and the Office for Environmental Protection (OEP). Initial policy commitments in the Environment Improvement Plan were deemed insufficient by the OEP (OEP, 2023a). Defra in July 2023 published its annual report on progress against its Environmental Improvement Plan which the OEP will respond to in early 2023 (OEP, 2023b). The UK also reports on its progress to the Convention for Biological Diversity (CBD) targets. The majority of targets (most recently the CBD Aichi 2020 targets) have not been met (JNCC, 2019). Globally, progress has fallen far short on most of the targets (CBD, 2020), with some limited successes such as the extent of protected areas expanding across the globe. However, the fundamental drivers of biodiversity loss have not been addressed (Oliver, 2020 & 2021).

The UK is also a signatory to the Kunming-Montreal Global Biodiversity Framework (GBF) and this, if successful, is expected to shape significant changes in our economy over the coming decade. Target 3 of the GBF (referred to as '30x30') aims to ensure that by 2030 at least 30% of land and ocean area "are effectively conserved and managed through ecologically representative, well-connected and equitably governed systems of protected areas [PAs] and other effective area-based conservation measures [OECMs]" (CBD, 2023). Importantly, the indicators for this target go beyond areal coverage and include key biodiversity areas coverage, Species Protection index, PA management effectiveness, PA Connectedness index, amongst others. In short, it is not only about quantity but also quality. In the UK, there are discrepancies on the scope of what constitutes a Protected Area which leads to very different estimates. According to a recent report by the House of Lords Environment and Climate Change Committee (Jul'23), only 6.5% of land in England meets the requirements for the 30x30 target whilst in the government response, the value is 26% (including 8% of protected sites and 24.5% protected landscapes). Interestingly, both estimates are from the JNCC Indicator C1: 26.4% (27.8% for UK) is the Protected Area estimate for land including all sites (38.2% for sea) whilst 6.5% (10.6% for the UK) is the estimate excluding "AONBs, NSAs and National Parks".

1.2. Theoretical underpinning to the NRRI

Extensive work over decades has explored the foundational role of nature in the economy (Dasgupta, 2021) and its relevance for specific sectors such as insurance (UNDP SIF, 2021). Initial work done by the Millennium Ecosystem Assessment and UK National Ecosystem Assessment for example developed conceptual frameworks for how natural capital provides ecosystem services (including provisioning, regulating and cultural ecosystem services) that underpin human prosperity and wellbeing. More recent work by the IPBES has highlighted the plurality of values beyond instrumental values (i.e. 'nature for humans') to encompass relational and intrinsic values (IPBES, 2022).

There are various approaches to classify the instrumental values of nature, for example:

- the Common International Classification of Ecosystem Services (CICES; cices.eu), developed from work on environmental accounting undertaken by the European Environment Agency, supporting contributions to the System of Environmental-Economic Accounting which is led by the United Nations Statistical Division.
- Nature's Contributions to People (NCPs) developed by IPBES.

These frameworks provide a categorisation of the diverse dependencies that humans have on ecosystems. However, they are not framed in terms of the specific risks faced from environmental degradation, in particular in terms of the impact and likelihood of such 'nature-related risks'.

1.3. How the NRRI was developed

We developed a 'long-list' of risks in relation to the IPBES Nature's Contributions to People categories. This set of risks was derived from the global risk scenario taxonomy presented in Ranger et al. (2023) and specified for the UK via an initial literature and elicitation by the project team. The risks were then mapped onto the IPBES NCP categories, while ensuring all NCPs had multiple risks associated with them (Figure 1.2). For example, the NCP category of pollination and dispersal of seeds relates to four related NRRI risks: i) loss of pollination service, biodiversity loss and impacts on mental health, multiple breadbasket failure and global food security repercussions).

Note, there are many nature-related risks that could potentially impact the UK economy and stability and no inventory of risks will ever be fully comprehensive. But, following the approach above, we can at least ensure that risks arising from the full range of nature-dependencies are encompassed. Also note that, based on the definition of nature-related risks arising from nature degradation, we do not include geological risks such as earthquakes or volcanic activity. The NRRI does not aim to repeat efforts and so does not contain direct-climate risks. However, it is impossible to fully separate nature and climate risks, as climate change exacerbates many of the nature-related risks (and vice versa). We capture these associations in the NRRI.

NCP category	NRRI
Habitat creation and maintenance	1. 2. 3. 4. 5. 6. 8. 11. 12. 14. 18. 22. 23. 24. 25. 27. 28. 29.
Pollination and dispersal of seeds	3. 12. 14. 24.
Regulation of air quality	1. 12. 14. 22. 23. 24. 27. 28. 29.
Regulation of climate	1. 2. 3. 4. 5. 6. 8. 11. 12. 14. 15. 17. 18. 22. 23. 24 25. 27. 28. 29.
Regulation of ocean acidification	2. 3. 8. 15. 18. 25.
Regulation of freshwater quality, location and training	1. 2. 3. 4. 5. 6. 8. 12. 14. 17. 18. 22. 23. 24. 27. 28. 29.
Regulation of freshwater and coastal water quality	2. 3. 6. 8. 12. 14. 17. 18. 22. 23. 25. 27. 28. 29.
Formation, protection and decontamination of soils	1. 2. 3. 4. 5. 6. 8. 12. 14. 22. 23. 27. 28. 29.
Regulation of hazards and extreme events	1. 2. 3. 4. 5. 6. 8. 11. 12. 14. 22. 23. 27. 28. 29.
Regulation of organisms detrimental to humans	2. 6. 8. 12. 14. 17. 18. 22. 23. 24. 25. 27. 29.
Energy	11. 27.
Food and feed	3. 12. 14. 18. 25. 28.
Materials and assistance	4. 5. 8. 11. 12.
Medicinal, biochemical and genetic resources	3. 17. 18. 22. 23. 27. 28. 29.
Learning and inspiration	3. 8.
Physical and psychological experiences	3. 8.
Supporting identities	3. 8.

Figure 1.2: Nature's Contributions to People from IPBES framework and the consequences of their degradation in terms of creating nature-related risks. See Figure 1.3 for legend explaining the NRRI symbols.

The project team developed plausible worst-case scenarios for how each risk might impact the UK economy and threaten financial stability. This was accompanied by an evidence statement based on a literature review pertaining to the likelihood and potential material impact of this scenario. The full evidence statements can be viewed in the Supplementary Material 1 accompanying this report. Note, these 'scenarios' are focussed on single risks, and later in this report (Chapter 4) we develop scenarios of multiple, compounding risks.

We then consulted experts to test and refine the NRRI. We involved 25 experts with backgrounds in environmental science (e.g. climate, air pollution, freshwater ecosystems, etc.) and financial risk. These experts were each allocated four risks and reviewed the evidence statements. They produced a score for each risk's perceived likelihood as either 'low', 'medium' or 'high' based on their estimate of the probability that the risk will materialise over the next three decades. They also scored the impact; assuming the risk did materialise the impact was scored as either 'low', 'medium' or 'high' based on an assessment of potential material impact on the UK economy.

For both these scores (likelihood and impacts), experts were asked to indicate their confidence as low, medium, or high, e.g. they might score a risk as high impact but with low confidence because there is large uncertainty about whether the extent of the impact would be so severe.

This estimate was based on the evidence contained in the risk inventory and their own expert opinion. Experts had the opportunity to comment on the evidence statements, i.e. whether they disagreed with any of the evidence, or whether any key evidence was missing; and these comments have been incorporated into the final version presented in Supplementary Material.

Assessing interactions between risks

It is important not to focus on single risks in a siloed way, since they do not occur independently. Some risks arise through shared drivers such as soil health degradation or climate change, whilst other risks have cascading interactions, whereby one risk occurring makes a second risk more likely. The importance of considering compound risks within scenario analysis was recently highlighted by the NGFS (NGFS 2023b).

In order to understand which risks might occur simultaneously - based on shared drivers or cascade interactions and feedbacks - the project team produced a table where associations between risks were scored according to the criteria in Figure 1.4 (see inset legend with scoring criteria). Experts had the opportunity to review and comment on the associations linked to specific risks allocated to them and these were used to refine the scoring and rationale.

Note, some associations between risks are obvious, such as between risk of air pollution caused by wildfire smoke and the risk of direct damage from wildfires. Readers may query why these individual risks were not grouped, but the modular approach allows flexibility in combining risks in different permutations; in this example because certain regions may be affected by smoke without fire impacts.

Dealing with 'missing' NRRs

As mentioned, no analysis of NRRs can be fully comprehensive, although we have ensured that risks represented in this inventory cover the full spectrum of Nature's Contributions to People (Fig 1.2). We recommend that the NRRI in this current report should be iteratively updated as new risks become apparent.

The UK National Risk register highlights acute risk threats to the UK, such as terrorist attacks and flooding. Work led by Cabinet Office is currently ongoing to appraise longer-term 'chronic risks', - i.e. challenges which build incrementally that, if left unchecked, can erode our economy, community, way of life and/or national security. In both cases, the wide variety of nature-related risks, both chronic and acute, are poorly characterised and we recommend that the NRRI in this current report could be incorporated into these 'live' risk registers.

As an example of this, following the Nature-Related Value at Risk (nVaR) analysis (Chapter 3) it became apparent that two risks related to 'water shortages impacting energy and agriculture' and 'critical resource supply chain disruption' were absent from the NRRI that was generated from the expert brainstorming process. The first of these risks is primarily driven by climate change (altered precipitation trends and rising temperatures) but also strongly mediated by land use affecting river flow rates and groundwater levels. Water shortages affect agricultural productivity directly, but also through regulated limits to water abstraction for irrigation and livestock rearing processes. Reduced flow rates also affect electricity generation through availability of water for cooling and hydroelectric power generation. The second risk is related to shortages of critical natural resources (e.g. minerals and metals for use in electric cars, computer chips, LCD screens etc) due to increasing global demand (e.g. for net zero transition) in combination with acute disruption affecting key trade routes from extreme weather events and geopolitical disruption. These disruptions are exacerbated by break down in free trade and increased market protectionism, leading to shortages for manufacturing firms, increasing prices and hampering economic growth.

These two additional NRRs were subsequently added to the inventory, and can be found detailed in the Supplementary Material 1 as NRR numbers 9 & 10. However, it should be noted they have not been through the same expert review and scoring process as have the other risks, although impacts of the risks have been informed by the quantitative nVaR analysis.

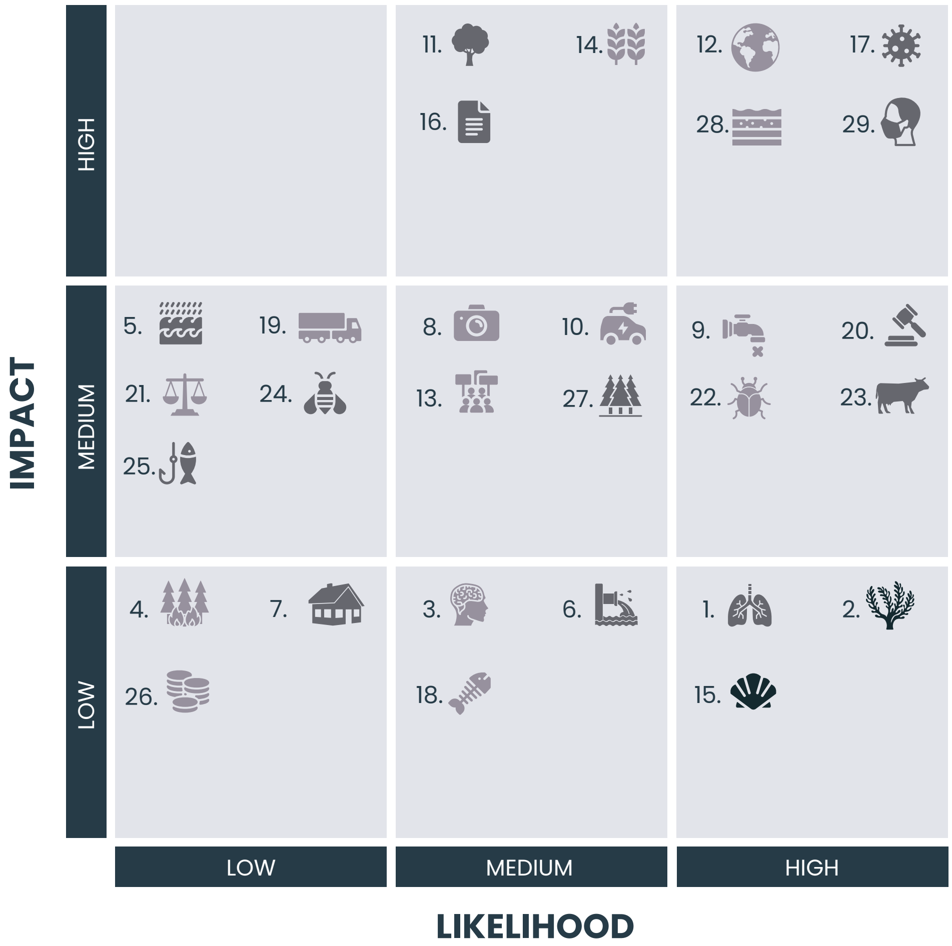
1.4. Results of the NRRI risk scoring

The results of the expert scoring of NRRI risks are shown in Figure 1.3, with mean likelihood, impacts and associated confidence scores shown in Table 1.1. The results of the assessment of association between NRRI risks is shown as an image in Figure 1.4, and with rationale statements as an Excel supplement to this report (Supplementary Material 2).

1.5. UK Outlook for nature-related risks

An important question for decision-making around nature-related risks is whether we can expect them to worsen or improve over time. Many NRRs are affected by the quality of UK habitats and species, which UK government data show have been declining over time (for full details please see Supplementary Materials) (Figure 1.5). The degradation of UK terrestrial and freshwater environments increase likelihood of NRRI risks 1-9. Overexploitation of fisheries and degradation of marine environments worsen risks 15, 18 & 25. Environmental change in other countries also affects the NRRs faced by the UK (NRRI risks: 10-29). These environmental trends and the specific risks they impact are detailed in the Supplementary Material 1.

The impacts of risks detailed in the NRRI are also highly contingent on environmental policy implementation both nationally and globally. Particularly important are the targets in the UK Government Environment Act 2021 along with international initiatives such as the Convention for Biological Diversity targets. In the Supplementary Materials, we describe such initiatives and reflect on their likely effectiveness at reducing the likelihood and impact of NRRs, and also how misaligned policy implementation could trigger transition risks (e.g. NRRI risks 7, 13, 16, 19, 20, 21, 26).



Mainly Domestic

1. Air pollution from wildfires
2. Algal blooms in water ecosystems
3. Biodiversity access and mental health
4. Direct damage from wildfire
5. Flooding due to deforestation and soil damage
6. Freshwater pollution
7. Housing asset risks due to policy and legal changes
8. Risks to tourism from nature damage
9. Water shortages impact energy and agriculture

Mainly International

10. Critical resource supply chain disruption
11. Deforestation and ecosystem tipping points
12. Global food security repercussions
13. Global food supply chain interruption from biodiversity and climate policy misalignment
14. Multiple breadbasket failure
15. Ocean acidification

Domestic and International

16. Acceleration of strict net zero and nature protection policies
17. Anti-microbial resistance
18. Aquaculture major pest or pathogen outbreak
19. Business impacts due to UK-only biodiversity policies
20. Corporate litigation cases
21. Government litigation cases
22. Grain crops pest / pathogen outbreak
23. Livestock disease
24. Loss of pollination service
25. North Sea fishery collapse
26. Reputational risk, stranded assets and fund withdrawal
27. Sitka spruce pest outbreak
28. Soil health decline
29. Zoonotic disease

Figure 1.3: The estimated likelihood and impact of NATURE-RELATED RISKS to the UK economy and financial system up to 2050. Scores were derived from an expert elicitation process with mean scores shown (also see Table 1.1). Confidence in scores is indicated by the colour of the risk symbol with darker shading indicating higher confidence. Risks numbered 7, 13, 16, 19 & 26 are transition risks, 20-21 are litigation risks, all others are physical risks.

Risk title	One sentence risk description	Risk type	Risk source and timeframe	Likelihood	Degree of confidence	Impact	Degree of confidence
1. Air pollution from wildfires	Air pollution from wildfires in an urban setting.	Physical	Either transboundary or domestic, both acute and chronic	2.5	2.83	1.83	2
2. Algal blooms in water ecosystems	Algal blooms reducing water quality in freshwater marine environments	Physical	Domestic (freshwater) and transboundary (ocean fishing), Acute	2.5	2.5	1.5	2.5
3. Biodiversity loss and mental health	Loss of biodiversity and reduced access to high quality greenspace exacerbating mental health problems	Physical	Domestic, chronic	2.2	2	1.8	1.6
4. Direct damage from wildfire	Direct damage from wildfire affecting built infrastructure and disrupting transport and communications.	Physical	Domestic, acute	1.25	2	1.5	1.75
5. Flooding due to deforestation and soil damage	Intensified risks of flooding due to increased frequency of storms/rainfall, or flooding linked to deforestation and soil damage	Physical	Domestic, acute	1.5	2.75	2	1.75
6. Freshwater pollution	Pollution of watercourses, standing waterbodies and ground waters causing health risks	Physical	Domestic, chronic	2	2.5	1.5	2
7. Housing asset risks due to policy and legal changes	Strict planning regulations create significant asset, underwriting and credit risks for housing developments and additional costs for homeowners	Transition	Domestic, chronic	1.33	2.33	1.33	2
8. Risks to tourism from nature damage	Damage to UK biodiversity impacts domestic and international tourist numbers	Physical	Domestic, chronic	2.2	1.8	2	2
9. Water shortages impact energy and agriculture	Water shortages in rivers, standing water bodies and in groundwaters lead to reduced agricultural productivity and impact energy supply and prices	Physical	Domestic, chronic with acute episodes	Not part of expert scoring process; see Methods			
10. Critical resource supply chain disruption	Supply chain disruptions of key aspects of natural capital (such as critical minerals) lead to shortages for manufacturing sector and industry impacts	Physical	Transboundary, chronic with acute episodes	Not part of expert scoring process; see Methods			
11. Deforestation and ecosystem tipping points	Deforestation driving tipping points in major global forest ecosystems (e.g. Amazon, boreal forests), which leads to acceleration of global heating	Physical	Transboundary, chronic leading to acute	2	2	2.75	2.25
12. Global food security repercussions	Food insecurity prompts or exacerbates mass human displacement both within and between countries	Physical	Transboundary, chronic with acute phases	2.5	1.75	2.75	1.75
13. Global food supply chain interruption from biodiversity-climate policy misalignment	Major global food supply chain interruptions related to biodiversity protection and misalignment with climate change cause food insecurity	Transition	Transboundary, chronic with acute phases.	2.2	1.2	2.4	2
14. Multiple breadbasket failure	Major cereal producers around the world face concurrent disruption due to acute impacts such as political instability, extreme weather, exacerbated by soil damage and disruption to fertiliser supply chains	Physical	Transboundary, acute	1.8	1.8	2.8	2.2

Risk title	One sentence risk description	Risk type	Risk source and timeframe	Likelihood	Degree of confidence	Impact	Degree of confidence
15. Ocean acidification	Dissolved CO2 in oceans increases acidity, decreasing ocean pH, and affects marine ecosystems	Physical	Transboundary, chronic	3	2.67	1.67	2.33
16. Acceleration of strict net zero policies	UK acceleration of strict net zero and nature protection policy, with misalignment within UK and between countries	Transition	Domestic and transboundary, Chronic	2.24	2.5	2.75	2.25
17. Antimicrobial resistance	Antimicrobial resistance affecting humans, animals/livestock, and the environment	Physical	Domestic and transboundary, chronic (with acute disease epidemic events)	2.67	2.33	3	2.33
18. Aquaculture major pest or pathogen outbreak	Intensive aquaculture leads to outbreaks of pests which decimate productivity.	Physical	Domestic and transboundary, chronic with acute phases	2.33	1.67	1.3	1.67
19. Business impacts due to UK-only biodiversity policies	Reduced competitiveness of UK industry due to biodiversity policies implemented in the UK only	Transition	Domestic and transboundary, chronic	1.6	1.6	2	2
20. Corporate litigation cases	Environmental damage prompts legal action against corporations	Litigation	Domestic and transboundary, chronic with acute phases	2.67	2.33	2	2
21. Government litigation cases	Failure to comply with environmental legislation prompts legal action against UK government	Government litigation	Domestic and transboundary, chronic	1.67	2.33	2	1
22. Grain crops pest / pathogen outbreak	Large cereal monocultures are susceptible to novel crop pest and disease outbreaks	Physical	Domestic and transboundary, acute	2.6	1.6	2.2	1.8
23. Livestock disease	An animal-borne disease caused substantial impacts of the livestock or poultry industry	Physical	Domestic and transboundary, acute	2.6	2.2	2.2	2.2
24. Loss of pollination service	Loss of pollinating insects in the UK affects top fruit productivity (e.g. apples) as well as other pollinator-dependent horticulture such as strawberries and field beans	Physical	Domestic and transboundary, chronic	1.75	2.25	1.25	2
25. North Sea fishery collapse	Collapse of fish stocks in UK fisheries	Physical	Domestic and transboundary, acute	1.67	2	2	2.67
26. Reputational risk and depository redistribution	Low confidence in management of environmental risks and/or stranded assets leads to mass withdrawal from retail banks	Transition	Domestic and transboundary, acute	1.67	1.67	1.33	1.67
27. Sitka spruce pest outbreak	Monoculture plantations of Sitka spruce are decimated by a major pest or disease outbreak	Physical	Domestic and transboundary, acute	2.2	2	2	2.2
28. Soil health decline	The loss of top soil through erosion and loss of soil biodiversity through heavy chemical inputs severely compromises crop yields and carbon storage	Physical	Domestic and transboundary, chronic	2.67	1.83	2.67	1.6
29. Zoonotic disease	Disease causing pandemic and major economic and financial disruption	Physical	Domestic and transboundary, acute	2.75	2.25	2.5	2

Table 1.1: Description of the NATURE-RELATED RISKS with type of risk, risk source and timeframe, and mean scores from the expert elicitation process. See Supplementary Material 1 for plausible scenarios for how each risk might play out over the next three decades with evidence statements on likelihood and potential impact.

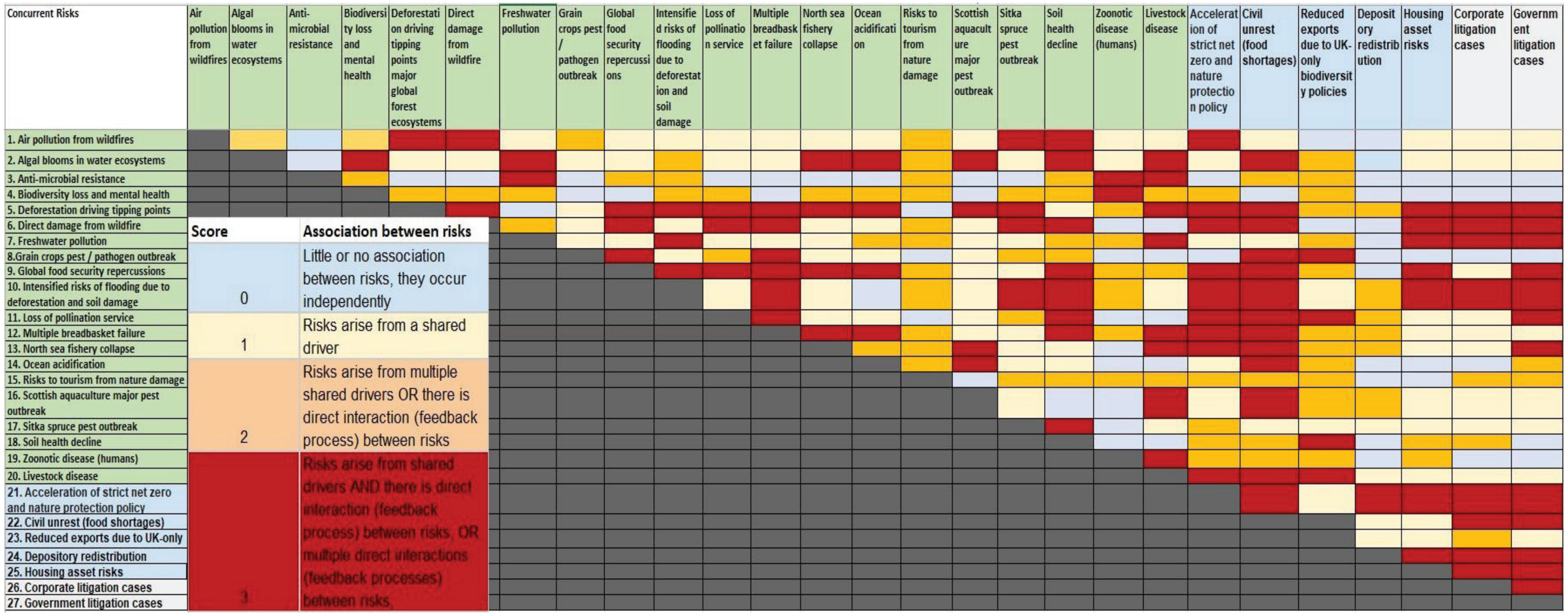


Figure 1.4: Associations between individual risks in the UK-NRRI. Strong associations (e.g. through shared drivers or feedback effects between two risks) are shown in deeper red. Rationale statements for the scores can be found in Supplementary Material 2. The inset legend shows the criteria used for scoring associations.

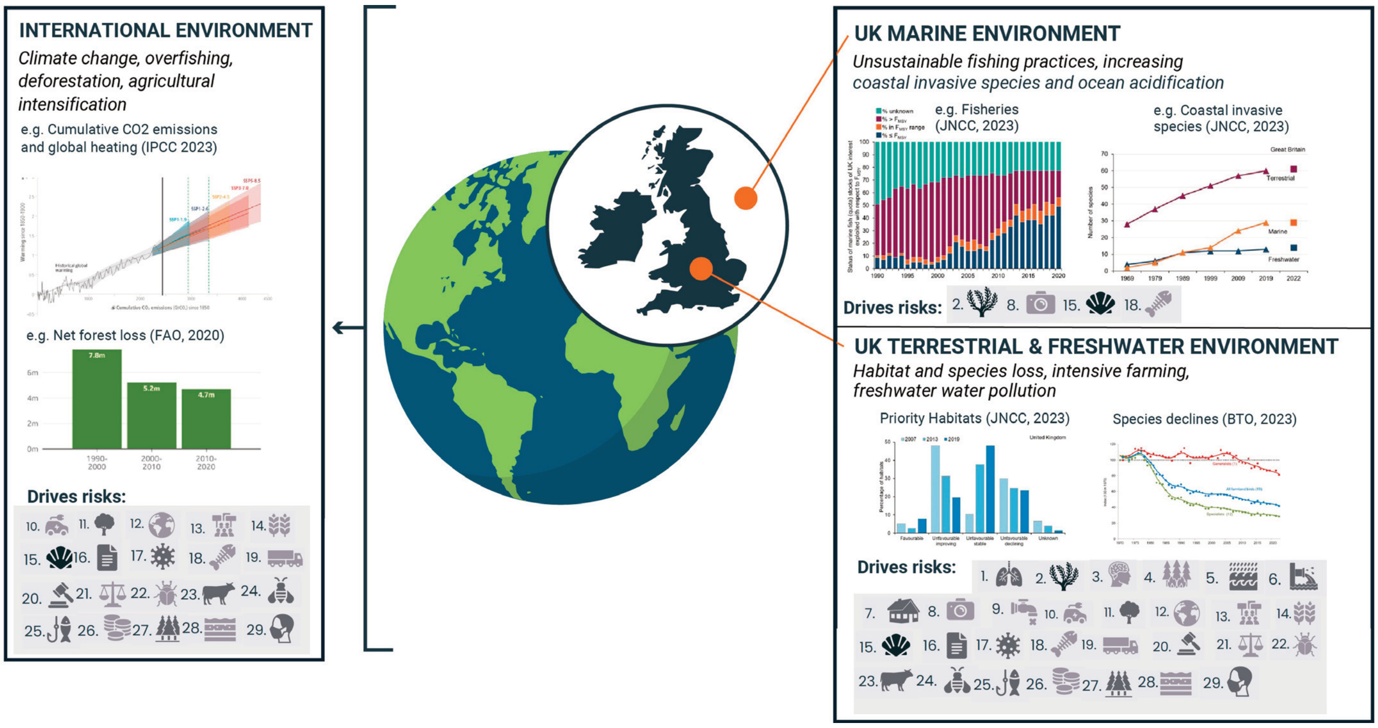


Figure 1.5: Nature-related risks faced by the UK arise from domestic as well as international environmental degradation (driving transboundary risks). See Figure 1.3 for risk symbols and descriptions.

1.6. Next steps/gaps in assessing nature-related risks

The analysis of nature-related risks in this report is not comprehensive, nor could any analysis ever be, given the VUCA (Volatile, Uncertain, Complex and Ambiguous) nature of the modern world (SysRisk, 2021). Nevertheless, we have aimed to ensure that the broad categories of our human dependencies on nature (cf. IPBES NCPs) have been adequately assessed, in terms of example risks that can arise from each of these. Further work could consider additional risks that were discussed as part of our expert elicitation process. Also, much of the evidence cited in the UK-NRRI is recent, signifying the knowledge underpinning these risks is still developing. Therefore, the likelihood and potential impact of risks may change as our understanding evolves. Similarly, new risks may emerge that we want to appraise (cf. 'horizon scanning' initiatives in government; Government Office for Science, 2023). Hence, we propose that the UK-NRRI should be a 'living document' with regular updates, similar to (or as part of) the UK National Security Risk Assessment, and subsequent 'chronic risks' assessments that are forthcoming (Cabinet Office, 2023).

The risks listed in the UK-NRRI should hopefully help financial institutions explore their vulnerabilities and exposures. The modular nature of the tabulated risks can also serve as 'LEGO bricks' for these actors to develop compounding scenarios. The concurrent risks table (Supplementary Material 2) can help to this end. An example of how to build and explore compounding risk scenarios features in Section 5 of this report.

Part A: Risk-Based Analysis

Nature-Related Dependencies and Risks to Economic Sectors

Chapter 2. Exposures to Nature-Related Risks

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2.1. Introduction

The first part of this report (Part A) focusses on sectors and assesses the dependencies of the UK economy and financial sector on different ecosystem services. This is the first step in quantifying risk. Chapter 3 then assesses the value at risk. Both chapters focus on physical nature-related risks, though we also include an analysis of the exposure to transition risks.

One of the core tools used to date to support financial institutions in assessing their dependencies on nature is the ENCORE tool, developed by UNEP-WCMC, Global Canopy and the UNEP Finance Initiative (UNEP FI). Indeed, the Bank of England (BoE) completed in-house analyses using this tool, referred to in the speech by Sarah Breeden in 2022[8].

This Chapter is divided into four parts. The first part of this chapter draws directly upon a new analysis completed by UNEP-WCMC and includes an analysis of the dependencies of UK banks and insurers on ecosystem services. The output is a sector-specific and ecosystem service-specific assessment of exposure. The full UNEP-WCMC dependencies report is included in the online Supplementary Materials. The second part, completed by UNEP-WCMC with the University of Oxford, combines the ENCORE tool with a multi-regional input-output (MRIO) model (EXIOBASE) to take into account the exposures of UK firms to global supply chains. From UNEP-WCMC, with inputs from SEI York, we include a mapping of these exposures against hotspots of natural capital depletion globally and a preliminary analysis that explores dependencies within the international supply chains of the UK's investment portfolio. Finally, we include analysis from the University of Oxford to explore the exposures to transition risks in the UK. All components draw upon financial portfolio data provided by the Bank of England at sectoral level, and include additional data collected from banks' own reporting available online.

2.2. Dependency Analysis

The ENCORE knowledge base maps how different production processes are potentially dependent on different ecosystem services. Each production process-ecosystem service link has a materiality rating, which can be Very High, High, Medium, Low or Very Low (as seen in Figure 3.1, below). These materiality ratings are based on available peer-reviewed and grey literature and expert input from sector practitioners. Therefore, each sector[9] has its own 'dependencies profile' (i.e., the list of ecosystem services it potentially depends on and their associated materiality ratings). Further detail is given in Annex 2.

[8] " Using the ENCORE database, internal Bank of England analysis found that over half [52%] of UK GDP and nearly three-quarters [72%] of the stock of UK lending exhibits dependence on ecosystem services – levels that might suggest elevated" Sarah Breeden 2022 https://www.bankofengland.co.uk/speech/2022/october/the-nature-of-risk-speech-by-sarah-breeden

[9] It should be noted that the ENCORE knowledge base was developed using the Global Industry Classification Standard (GICS) sector classification, whereas the data on UK banks and insurers exposures is split by NACE sector codes. As such, a conversion process needed to be conducted to be able to run this analysis.

Here, the ENCORE knowledge base is applied to information on the sectoral exposures of UK banks and insurers. It is important to note that this does not include any spatial information; i.e. the geographical distributions of these exposures.

The total value of assets of UK banks and insurers (bonds, loans and equity) analysed is £3.8 trillion, constituting £1.4 trillion bonds, £1.5 trillion loans and £0.9 trillion equities. This was based on a 2021 dataset made publicly available by the Bank of England, with bond, loan and equity data sub-divided by NACE sector code (and no geographical information). Of this, by far the largest sector is Finance and Insurance activities (Section K), which constitutes £2 trillion in total. Section K is not included in the direct dependency analysis to avoid biasing it. It is unclear where the finances within Section K are spent in the real economy and therefore it is difficult to assess the sector's real exposure to nature-related risks.

In Figure 2.1, the Sankey diagram shows how financing flows enter the economy on the left as either a bond, equity or loan, then flow rightwards and redistribute across NACE Sections. The size of the node of each NACE Section is proportional to the financial value (exposure) associated with it, with the biggest sectors located at the top of the diagram and the smallest at the bottom. Traveling rightwards, investments are again subdivided through production processes into ecosystem services upon which they depend. Similarly, the ecosystem services that underpin the highest financial value are located at the top of diagram. The sum of the heights of the diagram represents the total amount of exposures held in the portfolio.

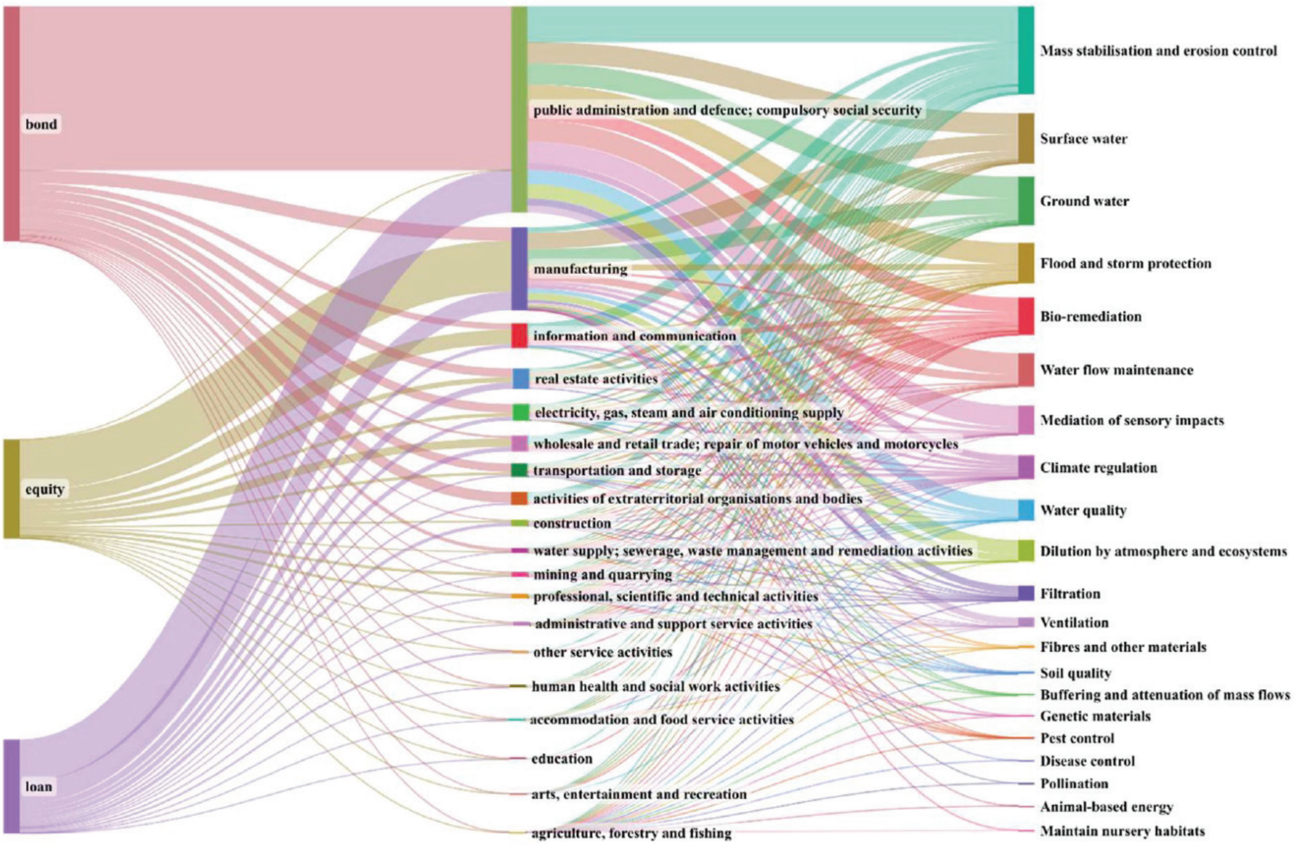


Figure 2.1: Sankey diagram of UK's financial exposures excluding Section K (Financial and insurance activities) and their dependencies on ecosystems services. The left-hand column shows asset classes from the dataset, and the size of the left hand flows show financial flows to NACE Sections (centre column). The right-hand flow uses the ENCORE knowledge base to identify dependencies between NACE Sections and ecosystem services (in the right hand column), and the size of the relationship is proportional to the strength of the dependency, weighted by the financial value attached with it.

More than half of the bond exposures in the dataset (£670 billion out of £970 billion in total bond exposures) flow to NACE Section O (Public administration and defence; compulsory social security), which includes many government bonds, or gilts. Most equity exposures (£210 billion out of £424 billion total), by comparison, are in NACE Section C (Manufacturing), with a smaller but still sizable flow (£74 billion) to Section J (Information and communication). The majority of loan exposures go to Section O (£175 billion, Public administration and defence; compulsory social security), followed by Section C (£75 billion, Manufacturing).

The analysis suggests that mass stabilization and erosion control is the ecosystem service with highest material dependency (combination of dependency score and financial exposure), and is the most frequently occurring ecosystem service, being directly depended upon by every analysed NACE Section. This ecosystem service is primarily provided by vegetation and soil, and relates to the reduced potential for landslides, subsidence, and sedimentation of water bodies. This comes out as the ecosystem service upon which most sectors depend because all industries are dependent on this for infrastructure and buildings. The risk of this service being disrupted is low when compared to other ecosystem services, and this is explored further in Chapter 3. The provisioning ecosystem service of regulation of quantity of surface water is the second most material ecosystem service and is directly depended upon by a large number of sectors.

The analysis shows that £930 billion (52% of the portfolio that could be examined) of UK bank and insurer financial assets are at least moderately directly dependent on ecosystem services, and of this £179 billion (10%) are highly or very highly directly dependent. Of all the asset types, equities have the highest dependence on ecosystem services, with 19% of equity exposures associated with high or very high dependencies. Note that this excludes Section K (Financial and insurance activities). Figure 2.3 shows the ranked dependency of each NACE Division on the ecosystem services on which it is dependent. This shows that surface water is ranked highest for most sectors.

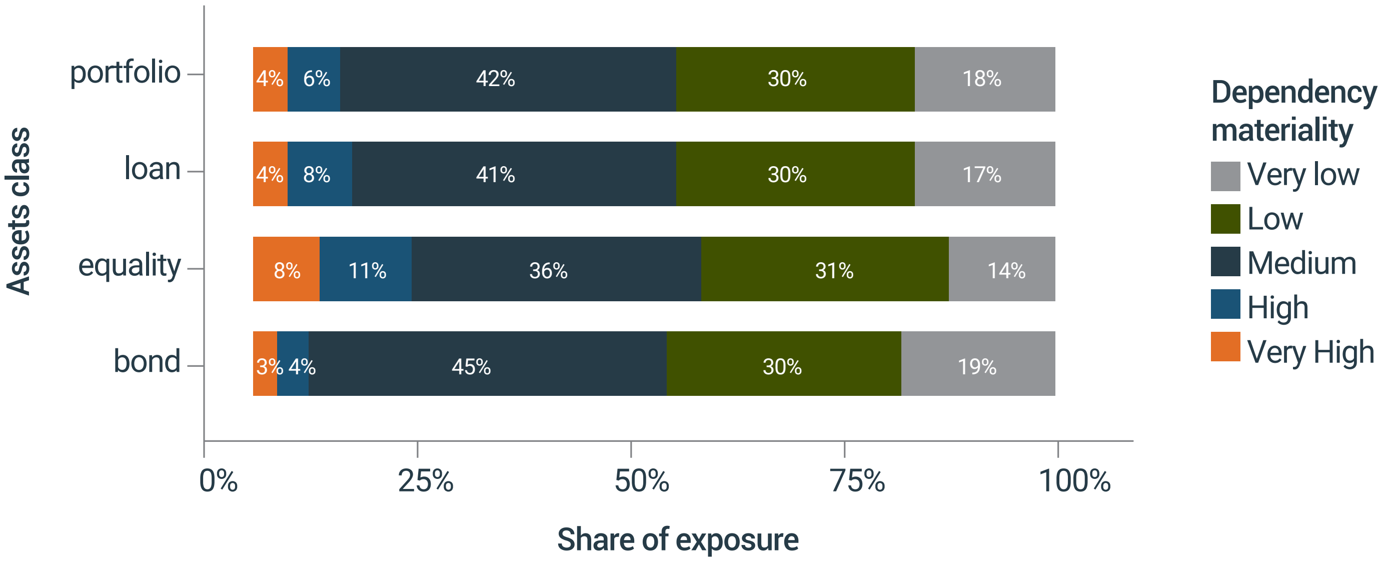


Figure 2.2: Percentage of the total portfolio value (the financial exposures of UK banks and insurers, excluding Section K) associated with each materiality category, showing the range of strengths of dependencies on nature in the portfolio.

Ecosystem Service	NACE Division: Forestry and logging	Crop and animal production, hunting and related service activities	Fishing and aquaculture	Electricity, gas, steam and air conditioning supply	Manufacture of chemicals and chemical products	Manufacture of basic metals	Manufacture of machinery and equipment n.e.c.	Manufacture of computer, electronic and optical products	Real estate activities	Public administration and defence; compulsory social security	Average of Ranks
Surface water	1	1	1	4	1	1	1	1	1	2	1.4
Flood and storm protection	3	3	4	1	2		1		4	2	2.5
Mass stabilization and erosion control	4	5	6	2	3	4	3		3	1	3.4
Climate regulation	2	4	2	3	7	3	4	4		4	3.7
Water flow maintenance	5	5	7	5	5	2	1			2	4.0
Ground water	8	9	9	6	1	1	1	1	2	2	4.0
Water quality	9	2	3	7	6		2			3	4.6
Disease control	6	7	6								6.3
Soil quality	6	5	5	11							6.8
Dilution by atmosphere and ecosystems	14	10	9		8		2	2		3	6.9
Bio-remediation	12	10	9	9	9		5	5	3	3	7.2
Filtration	13	11	10	8	8		4	4	4	4	7.3
Fibres and other materials	7	8	8	10	10			3			7.7
Pest control	6	7	6	12							7.8
Buffering and attenuation of mass flows	10	6	5	12							8.3
Mediation of sensory impacts	18	17	14	12	4		1		3	2	8.9
Ventilation	16	14	11		9		4			4	9.7
Pollination	11	13	10								11.3
Genetic materials	14	12	9		11						11.5
Animal-based energy	15	16	13								14.7
Maintain nursery habitats	17	15	12								14.7

Figure 2.3: Ranked dependency of each top 10 NACE Division on each ecosystem service. In each column, a value of 1 represents the ecosystem service upon which the NACE Division is most dependent (i.e. it has the highest dependency rating)[10].

[10] Water supply services reflect the combined ecosystem contributions of water flow maintenance, surface water, ground water, water quality, and other ecosystem services to the supply of water of appropriate quantity and quality to users for various uses including household consumption. As such, any mention of surface water and ground water in this report should be understood as ecosystems' contributions to the regulation of quantity and quality of water at sufficient levels.

2.3. Assessing Dependencies on Nature Internationally

Given that the UK is a highly globally interconnected economy, it is essential to consider both domestic and international risks. There are three main channels through which the rest of world can directly impact UK financial institutions upstream (Figure 2.4): firstly, financing UK entities that depend on overseas supply chains; secondly, via direct financing of entities overseas (both financial institutions and other firms, but could also include sovereign bonds); thirdly, financial flows to foreign direct investments (i.e. ownership). The rest of the world can also impact the UK in many other indirect ways, assessed in Part B.

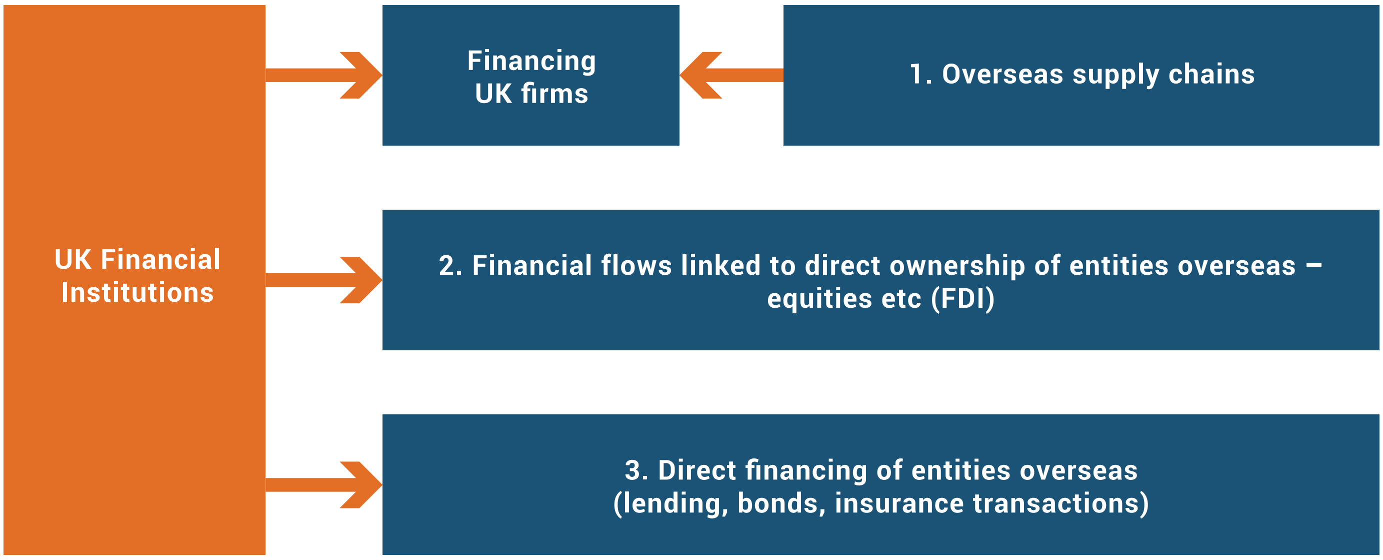


Figure 2.4: Illustrating financial flows from UK financial institutions with an international element.

In this project, our focus is on (1), albeit we include preliminary analysis of (2) and (3). We proxy for overseas supply chain exposures of UK firms through building a multi-regional input-output (MRIO) model using EXIOBASE MRIO tables. MRIO tables relate the production of goods and services in one country to production in another country. Similar to Svartzman et al. (2021), EXIOBASE is used therefore to assess upstream dependencies.

For (1) – overseas supply chains - dependencies are assessed for each country and the MRIO model is used to estimate the implications for dependencies of UK firms and subsequently for the UK financial sector. For example, if a product is assessed to have very high dependency, but it constitutes only 1% of the input to a sector in the UK, then the dependency is assumed to be much lower. This is a simplification as arguably some inputs will be more critical than others, but it is a sufficient first order approximation. Full results are presented in Chapter 3.

A challenge encountered in this analysis is that the financial dataset[11] used does not include a spatial dimension; it includes only the sector distribution of UK bank and insurer portfolios. The second component (2) is assessed using the original data disaggregated regionally and by sector using the EXIOBASE tables, and following the same pattern as observed in the UK's Foreign Direct Investment data (Box 2.1). The value of outward FDI flows (i.e. investments made by UK companies in companies abroad) was £74.8 billion in 2020 and the value of the UK's outward investment position abroad (i.e. the stock of UK FDI invested abroad) was £1.8 trillion[12]. To assess (3), additional information is collected from the Pillar 3 reports of the seven largest UK banks, and the results are presented in Chapter 3.

[11] This dataset, published by the Bank of England includes around 90% of the UK banking and insurance system's total assets for the fourth Quarter of 2021] (the exact date of the dataset is 31 December 2021). The dataset includes sub-sectoral exposure of three types of assets in UK banks' and insurers' portfolios: loans, bonds and equities. The exposure coverage includes loans, bonds and equities for banks, and bonds and equities for insurers. The sample of banks includes all UK-domiciled banks at the highest level of consolidation.
[12] https://commonslibrary.parliament.uk/research-briefings/cbp-8534/

It is estimated that the £3.8 trillion in assets from UK banks and insurers are dependent on a wider set of assets through supply chains (domestic and international), which may represent approximately £5.8 trillion of assets, of which £3.2 trillion, or 56% of the total upstream exposure are highly or very highly dependent on nature. This demonstrates the importance of assessing overseas exposures.

Box 2.1: Assessing the dependencies of Foreign Direct Investment.

In the absence of geographically explicit data, the first step was to estimate regionally and sectorally disaggregated financial exposures by combining the dataset on investment by sector of UK banks and insurers with ONS Foreign Direct Investment data. A coarse assumption was made here that 87.5%[13] of the UK exposures are held in the UK, and the remaining 12.5% is held overseas, and the 12.5% held overseas was held in a pattern that mirrored FDI investments. SEI York then ran this disaggregated input data (financial exposures by sector and region) through the EXIOBASE MRIO (Stadler et al. 2018) to provide an estimate of where financial exposures lie in the sectors upstream of those in the data published by the Bank of England.

Triangulate input financial data by sector

- Disaggregate across EXIOBASE regions, splitting proportionally on assumption of 87.5% domestic investment, 12.5% overseas
- Regionally disaggregate BoE data using FDI data from ONS

Run analysis through EXIOBASE

- Use EXIOBASE MRIO to compute upstream dependencies for each sector and region

Extract resulting financial flows

- Shows resulting upstream financial exposure by NACE section and EXIOBASE region

Simplified methodology for assessing upstream financial exposures from the Bank of England dataset, using EXIOBASE

The upstream financial exposures (by EXIOBASE region and NACE Division) were combined with the nature dependency ratings from the ENCORE knowledge base. From this, the upstream financial exposures associated with NACE Divisions with a High or Very High dependency on nature were calculated. This came to £3.2 trillion, or 56% of the total upstream exposure. This shows that, while 10% of the UK's first order (direct) dependencies from the ENCORE knowledge base are very highly dependent on nature (excluding Section K, as seen in Figure 2.2), a much larger proportion is highly or very highly dependent on nature within the sectors that supply the UK's financial investment portfolio.

[13] It is important to note that an assumption was made that 87.5% of the UK exposures are held in the UK, and the remaining 12.5% is held overseas. This was an informed estimate based on two data sources, which was necessary to make given the lack of spatially explicit information in the primary dataset. The distribution of that 12.5% overseas element was assumed to be split across sectors in the same proportions as found in the ONS Foreign Direct Investment dataset. In addition, also adding the hotspots of natural capital depletion moves beyond a static assessment of ecosystem services status. This estimate is based on two data sources. The level of investment in the UK, recorded as gross domestic fixed capital formation in GDP calculated through the expenditure approach (https://www.ons.gov.uk/economy/grossdomesticproductgdp/datasets/grossfixedcapitalformationbysectorandasset) and data on Foreign Direct Investment, both into and from within the UK (https://commonslibrary.parliament.uk/research-briefings/cbp-8534/). Subtracting the flow of investment from outside the UK from the amount of investment in the UK (as recorded in GDP statistics) gives a proxy of the investment in the UK from within the UK, data on foreign investment from within the UK gives a proxy of the level of investment that the UK, as a whole, directs overseas. Both data sets were looked at for 2021, the same year as the data for bonds, loans and equities. Therefore, assuming these financial assets follow a similar pattern to the investments recorded in GDP and FDI data, we can approximate the share of investment that will be domestic and international.

2.4. 'Exposure at risk': overlaying dependencies with data on the state of nature

As a proxy for the state of nature, the Global Hotspots of Natural Capital Depletion Layers, developed by UNEP-WCMC (UNEP-WCMC 2021) were used, specifically the combined terrestrial layer for natural capital depletion. This layer assesses how fast natural capital is being depleted globally, looking at the depletion rates of four different natural capital assets: atmosphere, biodiversity, soils and sediment (retention capacity), and water. Hotspots of depletion are defined as areas within the top 20% of relative depletion values for each of the four natural capital assets globally.

The data on hotspots of natural capital depletion (aligned to EXIOBASE regions) was combined with ENCORE dependency ratings by NACE Division, and the upstream financial exposure (by EXIOBASE region), as described in Box 2.1. We note a limitation of this analysis that the split of the investment portfolio within and outside the UK is likely to underestimate the proportion of investment outside the UK as it only accounted for FDI. Ideally – given the spatially explicit nature of nature-related risks – more geographically specific investment data would have been used. Nonetheless, (i.e. even with assuming a potentially greater proportion of investments are held domestically), we find that 44% of the upstream economic activity is at particular risk as it is found in sectors and regions where high nature dependency and high rates of natural capital depletion are co-located. For this 44% of upstream activity, the degradation of natural capital is highly likely to lead to the loss of ecosystem services on which that economic activity depends.

Further information on this analysis can be found in the online Supplementary Materials. Chapter 3 advances this analysis further through incorporating additional data to model the potential financial risk associated with this and shows the distributions across countries.

2.4. Exposure to a nature-positive transition in the financial sector

The transition to a more nature-positive economy will bring both opportunities and risks for UK firms and the UK financial sector. The scale of the risks as compared to the opportunities depends on how well financial institutions can anticipate and adapt to the changes, but also how the impacts on the real economy play out. This will partly depend upon the effectiveness of UK government policy. A delayed or disorderly transition will be more costly. The Principles for Responsible Investment provided an Inevitable Policy Response scenario (FRS+Nature[14]) that tries to capture the main policy levers for nature alongside climate. This includes policies to protect biodiversity hotspots, along with regulation mandating restoration of degraded land, and emerging legislation and targets for biodiversity outcomes that support the development of voluntary biodiversity credit markets. The impacts the scenario included increases in the price of deforestation-linked commodities, changes in demand for meat, shifting bioenergy, changes in soft commodity supply chains in response to changing policies and reputational and liability risks, and growing opportunities related to nature-related foods, services and assets.

UK firms in some sectors could see higher costs and reduced demand as part of the nature-positive transition. The UK is a signatory to the Kunming-Montreal Global Biodiversity Framework and associated package of decisions, requiring meeting a set of targets by 2030, including the '30 x 30' goal (Target 3 of the GBF that 30% of areas are effectively conserved and managed by 2030). Defra have already outlined an Environmental Improvement Plan for restoring biodiversity, water quality, air quality and biosecurity (Defra, 2023). However, current policy commitments to achieve this are deemed insufficient by the Office for Environmental Protection (OEP, 2023) and so further policies will likely need to be put in place to meet commitments. This could lead to transition costs in terms of higher costs for consumers (e.g. higher water and energy bills) due to stringent environmental regulation and taxes passed on from service providers and increased operating costs and transport cost. Companies around the world could see similar impacts at different rates. Rapid transition could lead to certain sectors suffering asset stranding.

[14] https://www.unpri.org/inevitable-policy-response/ipr-forecast-policy-scenario—nature/10966.article

For example, major policy initiatives to drive food system transition towards lower environmental impacts could lead to certain sectors (e.g. beef) with stranded assets, significantly higher costs and market risks. Where UK sectors affected by additional environmental protection costs also operate in international markets (e.g. livestock production, electric vehicles) then there may be trade and competitiveness impacts. Some studies suggest a 'pollution haven' effect, with imports of pollution- or energy-intensive goods increasing in response to tighter regulation. However, the effects tend to be small and concentrated in a few sectors and overall, the effect may be overwhelmed by other determinants of trade such as skilled labour availability.

UK firms and the financial sector are also well-placed to capture the opportunities from a nature positive transition. This includes developing new types of more sustainable products and services, such as alternative proteins and regenerative agriculture, and new asset classes.

We conduct a preliminary analysis and find that 35% of the banks' holdings are significantly exposed to transition risks, in particular through media scrutiny, pollution and their impacts on protected and conserved areas (Figure 2.5). To provide preliminary insights on the potential exposure to transition risks and opportunities in the UK, the University of Oxford collected data on the sectoral and geographical exposures of the top seven banks in the UK and conducted a preliminary risk screening, using the methodology of the WWF's Biodiversity Risk Filter (Annex 3). Combined assets with a value totalling more than £1 trillion were analysed.

We find that banks are not homogenously exposed, with the holdings of some banks significantly more exposed to transition risks. The analysis suggests that international banks tend to have the highest-risk portfolios with 53% and 50% of their holdings exposed respectively. Other analysed banks were found to be less exposed and two banks had only around 10% exposure. While the sectors with the highest risk and the risks most exposed to in portfolios were fairly consistent across all banks, more variation was found in the sectors with the highest exposure by value, corresponding to the differing sectoral holdings in each banking portfolio. Overall, the most exposed sectors we identified as: Agriculture, forestry and fishing; Manufacturing; Construction; Mining and quarrying; and Transport and storage.

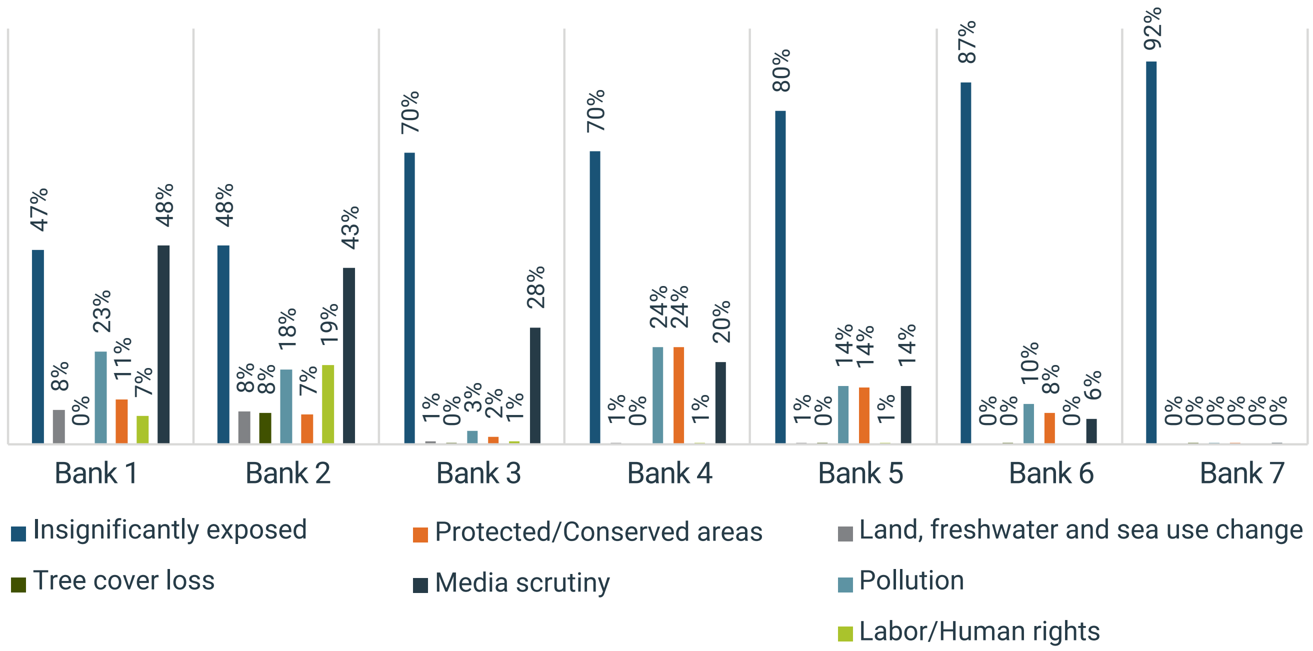


Figure 2.5: Proportion of bank holdings significantly exposed to at least one transition risk. Variations in exposures by sector arise when activities in certain geographies are considered significantly exposed, but not in others. Where a sector is 100%, it demonstrates that the sector is exposed to nature-related transition risk in any geography.

Chapter 3. Nature-Related Value at Risk (nVaR)

Authors: Nicola Ranger, Jimena Alvarez, Juan Sabuco, Emma O'Donnell, Michael Obersteiner, Tom Harwood, Anna Freeman and Estelle Paulus

3.1. Introduction

The nature-related Value at Risk metric developed in this Chapter aims to capture the likelihood that an ecosystem service will be materially disrupted in a given year, the severity of this impact, and the potential scale of the impact on firms and the sector overall. The dependency analysis described in Chapter 2 gives information about the exposure of sector output to ecosystem service depletion. It does not provide any information about the likelihood of an impact or the scale of that impact in financial terms if it occurred.

The methodology to translate ENCORE dependencies to sector production was outlined in Ranger et al. (2023) for five ecosystem services and is summarised here. This forward-looking risk metric (the nature-related Value at Risk, or nVaR) captures the potential impact at an aggregate sector level in terms of reductions in sectoral production; and is analogous to the Climate Value at Risk metrics produced for climate-related financial risk analysis (e.g. Dietz et al. 2016)[16]. This index-based approach that allows a more comprehensive representation of the relative risks across sectors, countries and ecosystem services, compared for example to an Integrated Assessment Model, albeit with less granularity. Uniquely, it captures both the direct risks to sectors in the UK (also referred to as first-order dependencies) and the indirect risks arising through domestic and global supply chains (also referred to as third-order dependencies) by incorporating data on the state of natural capital and vulnerabilities globally, alongside multi-regional input-output (MRIO) tables.

In this project, the Ranger et al. (2023) methodology is extended to eighteen ecosystem services and updated to represent UK-specific vulnerabilities. It is also applied to financial portfolios using the data for seven major banks discussed in Section 2.3. Importantly, the metric represents aggregate risk to a sector, and does not account for non-financial (e.g. labour productivity) or the second-order effects (e.g. inflation) that are identified in the NRRI and explored further in Part B. It is also important to note that the nVaR metric does not account explicitly for changes in prices or demand, or substitution effects; it effectively assumes that a loss of production in one supply chain translates to an equivalent loss of production at a sector level. Nonetheless, the metric provides a useful proxy to test and compare sensitivities to nature-related risks across supply chains.

3.2. Methodology

In summary, the methodology has three components (below) and illustrated in Figure 3.1.

Firstly, estimation of probable maximum loss (L) to a sector (s) and country (c) for a specific ecosystem service (e) (Ls,c,e): ENCORE dependency scores per sector are used to generate estimates of direct and indirect nature-related maximum exposures for each country through using the EXIOBASE input-output modelling approach, building upon the approach initially developed by Svartzman et al. (2021)[15]. This core method is consistent with that introduced in Chapter 2. A limitation of using EXIOBASE is the lack of geographical coverage for lower middle and lower income countries, but it is used here in this demonstrator approach given its wide coverage of sectors. This metric is a measure of the economic exposure.

[15] To calculate pollination risks, we adjusted dependency scores from ENCORE to represent the differential dependencies across different crop types for agriculture included in EXIOBASE; specifically setting wheat, rice and cereals to low risk and fruits and nuts to medium-high risk in line with the literature. For all other sectors, we use the ENCORE dependency scores.

[16] It is not the same as the backward-looking empirical VaR used in some traditional financial analyses.

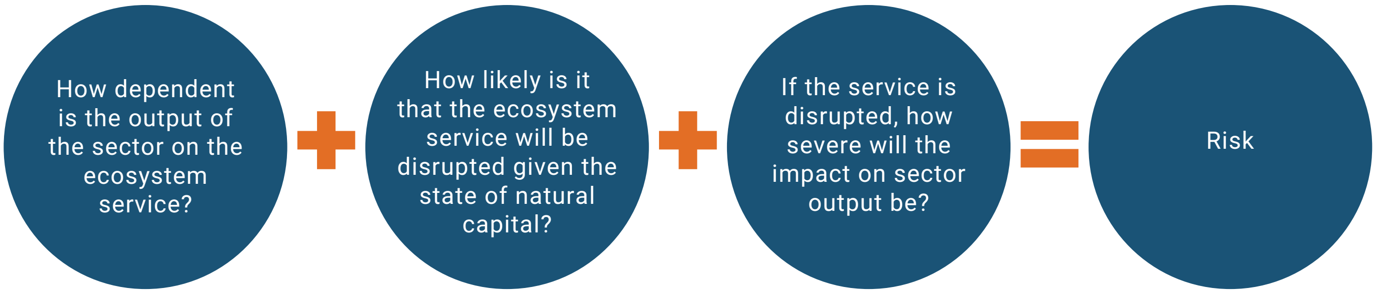


Figure 3.1: Illustration of the nVaR risk assessment methodology

Country- and ecosystem service-specific hazard-vulnerability composite index (Rc,e): Generating composite hazard-vulnerability indices that represent the likelihood that an ecosystem service is degraded and the potential magnitude of loss. The index is defined for each ecosystem service and country (Figure 3.2). As well as various indicators of the state of ecosystem services, the index includes a metric of national vulnerability and adaptive capacity (from the Notre Dame Global Adaptation Initiative, ND-GAIN) to represent the country-specific vulnerability. The effect of this vulnerability metric is to generally weight more advanced economies as lower risk, and less wealthy economies as higher risks, based on their assumed capability to respond and adapt. For the UK, in a few cases, the index is adjusted given other information sources to ensure the representation of UK hazards and vulnerability is well calibrated. For example, we assume that nVaR is very low for events below a return period of 1 in 100 (Jenkins et al. 2021).

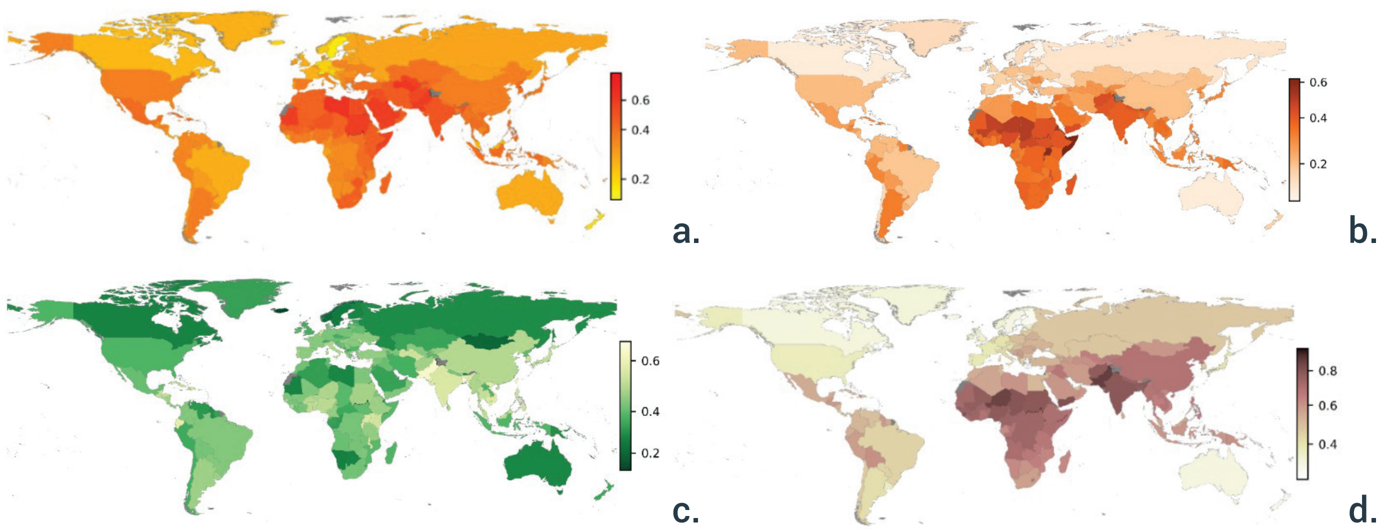


Figure 3.2: Global maps of hazard-vulnerability indices: (a) Surface water; (b) Water quality; (c) Pollination; (d) Ventilation (air quality risks). Hazard-vulnerability scores (0-1). Source: Ranger et al. (2023)

Sector-specific vulnerability distribution (Lc,s(P)): This distribution is calibrated to historical distribution of sector output over 30 years (1992-2022) using data from the World Bank's World Development Indicators database. This effectively places an upper bound on the greatest possible Nature-Related Value at Risk (nVaR) aligned with historical volatility for the sector. It could be argued that this is conservative, as risks in the future are likely to go well beyond historical experience. However, given that we use global sector timeseries for the analysis, for the UK, risk can go outside of historical experience. Nonetheless, this assumption limits the suitability of the method for long-term risk analysis, given that it does not account for the potential for catastrophic loss of output. In this report, all Value at Risk (nVaR) estimates are expressed at the 99th percentile (1 in 100 year event or 1% annual probability).

Box 3.1: Challenges in interpreting ENCORE dependencies for financial risk analysis

The ENCORE knowledge base was effectively developed to support portfolio risk screening, and was not designed to be used for financial risk analysis. There are therefore several challenges in interpreting the ENCORE dependency materiality ratings for risk analyses that we attempt to address through the methods used in this project:

- **The overlap between the ecosystem services.** Each of the ecosystem services captured within the ENCORE tool shares common underpinning natural capital assets, and - more importantly for financial risk assessment - they are not fully independent. This leads to potential double counting of risks when combined. Examples here are water-related ecosystem services such as filtration, ventilation, dilution and water quality; or regulation of quantity and quality of groundwater and surface water. This means that it is impossible to combine the risks from different ecosystem services to calculate the overall risk to a particular sector without careful analysis of the correlations across ecosystem services. For this reason, ENCORE alone cannot be directly used to estimate quantitative sector-based financial risks. To alleviate this issue, in this Chapter we do not present results for all services that have a high overlap and do not sum them.
- **ENCORE also includes insufficient quantitative information on dependencies for our needs, and so needs to be supplemented with additional information from empirical analyses or models to calculate financial impacts.** In this project, we follow the approach of Svartzman et al. (2021) to quantify dependencies. However, a high dependency in one sector does not necessarily translate to high financial risk. We partially correct for this through our approach to combining ENCORE dependencies with hazard and vulnerability data. However, the method has weaknesses when used to compare ecosystem services that have very different types of benefits to people, such as mediation of sensory impacts (e.g. mental health) versus surface water.
- **Insufficient information on how to combine ecosystem services.** For example, if a sector has high risk for one service and moderate for another, is the combined effect the sum, the maximum, the average or something else. For this reason, in this Chapter we do not combine the ecosystem services. In the scenarios formation process in Chapter 4, ecosystem services are combined but only where there are clearly independent.
- **Sector focus:** ENCORE is focussed on a set of economic activities (named production processes), and therefore does not alone allow capture of the wider range of risk transmission channels from nature to finance, including the impacts on fixed capital (e.g. buildings and infrastructure) and macroeconomic impacts and feedbacks through prices, changes in public expenditure, private investment, costs of capital, etc.
- **Definition of dependencies.** The way ecosystem services are defined in the Common International Classification of Ecosystem Services (CICES; used as the basis for ENCORE) creates challenges. For example, it is unclear to what extent labour productivity is already incorporated into the sector dependencies, or how risks to fixed capital (buildings and infrastructure) is represented under the flood risk dependency.
- **Lack of geographical information.** While ENCORE can be combined with spatial data to provide a spatial dimension, dependencies are assumed to be the same across all countries. In this method, we counter this with a country-score. Updates to ENCORE's knowledge base, planned for later in 2024, will also lay the ground for more spatial granularity in ENCORE-based assessments.
- **Geographical correlations of risk.** Care must be taken in summing up risks across countries to avoid overestimating risks through not accounting for the spatial correlations of events (e.g. a major flood is not likely to hit every country at the same time, so care must be taken in interpreting the 'flood' dependency). In this preliminary work, we correct for this through calibrating to published studies.

We note several limitations of this approach. Some of these are inherent within ENCORE (e.g. Box 3.1). A major limitation derives from the lack of empirical data on how the disruption to ecosystem services leads to economic losses to calibrate and validate the analysis. The lack of granular national/sub-national ecosystem service data means that the analysis is limited to countries, yet there will be significant variations within a country and this could mean underestimates or overestimates of the risk. For the UK, we conduct extensive validation of components and/or the final VaR against the literature where this exists. The method also does not account for recurrent events; it provides an annualised estimate of Value at Risk.

3.3. Findings: Sector nature value at risk (nVaR)

Figure 3.3 shows a comparison of the level of exposure of different economic sectors in the UK with the level of Nature Value at Risk (nVaR). The exposure analysis suggests potentially trillions of GBP at risk from the depletion of natural capital. The annualised nature-related value-at-risk (nVaR) is inevitably much smaller. This is because this metric takes into account the likelihood that the ecosystem service will be materially disrupted in a given year, the severity of this impact, and the potential scale of the impact on firms and the sector overall. For example, the analysis suggests around 97% of GDP is exposed to mass stabilisation and erosion control; in Chapter 3, we explained that this is because this service relates to stable land upon which all buildings and infrastructure depend. However, in reality, the evidence is clear that the likelihood of an earthquake or landslide wiping out 97% of UK GDP is very low.

A second important conclusion of the analysis is that the ranking of risks is different to the ranking of dependencies. For example, the dependency analysis suggested that the highest dependency in the UK is on the Mass stabilisation and erosion control ecosystem service, followed by flood and storm protection. In the nVaR risk analysis, these two ecosystem services are ranked lower. The reason for this difference between exposure and risk is that while there is high exposure to mass stabilisation and erosion control in the UK (e.g. all buildings and infrastructure rely upon stable ground), the chance of buildings becoming destabilised due to soil erosion or landslides and leading to financial impacts is relatively low. Similarly, while a large portion of buildings and economic output in the UK are potentially exposed to some flooding, the likelihood of large swaths of the UK being impacted simultaneously by major flood with catastrophic national-scale impacts is small. For example, Bates et al. 2022 suggest that losses (to buildings only) caused by 1-in-100 year flood events in the UK are just under £5 billion under a high climate change scenario; and at the upper end of projections, the Foresight Future Flooding report suggested just over £25 billion worth of losses due to average annual damages by the 2080s under a high climate change scenario incorporating potential changes in land-use, urbanisation and environmental regulation.

Figure 3.3: Comparison of Exposure and Value at Risk (total across sectors)

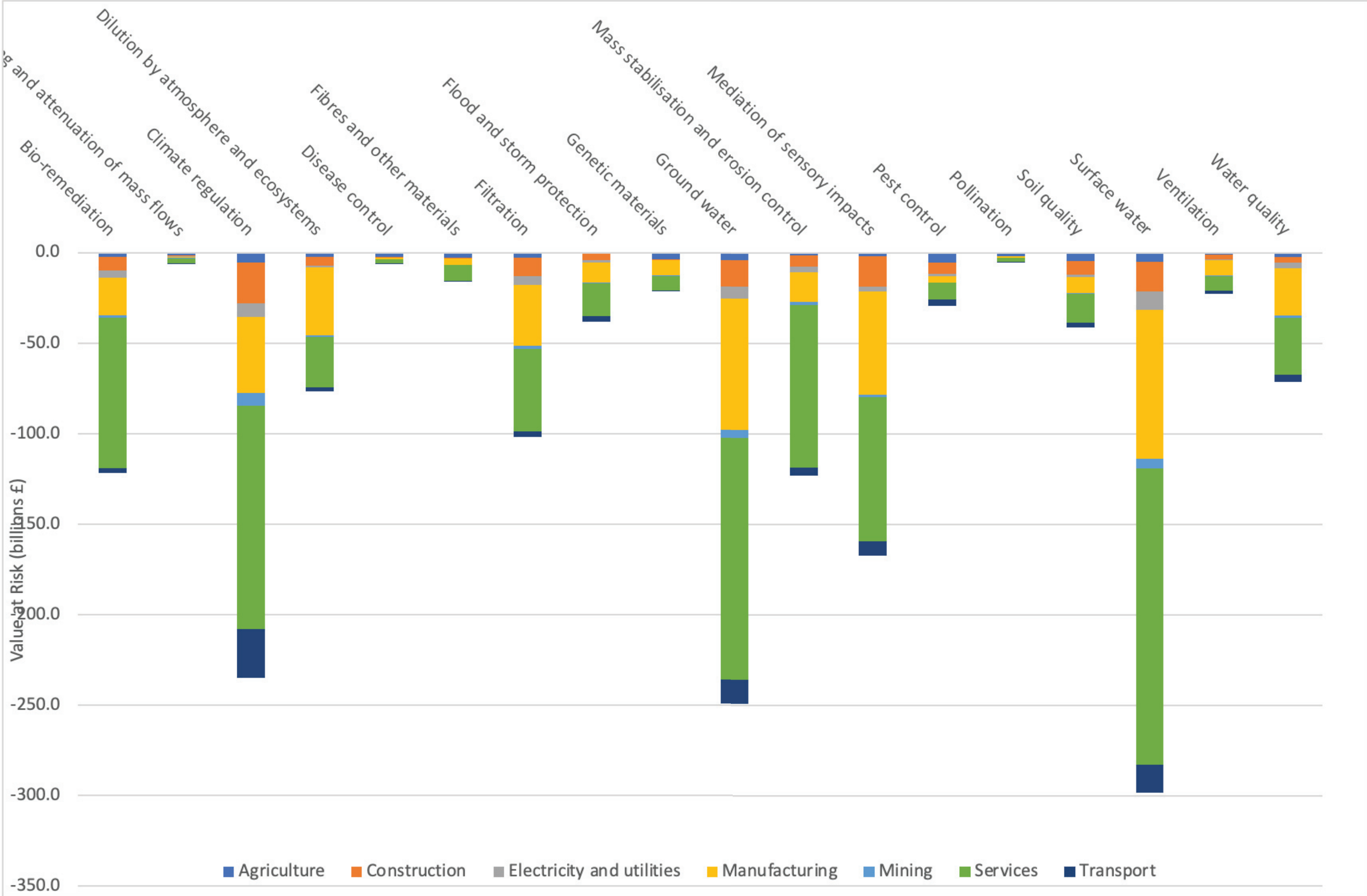


Figure 3.4: Preliminary estimates of annualised Value-at-Risk (1 in 100 year) (direct + indirect).

The analysis suggests the most significant risks relate to water and climate regulation, with nearly £300 billion at risk due to water scarcity alone (ground water and surface water) (Figure 3.4). Reduced climate regulation capacity emerges as the second highest risk after water. This represents the service provided by nature in regulating the climate, including for example, urban greening leads to a reduction of the urban heat island via cooling through transpiration or changing wind dynamics. The links to drought also mean it influences water-related risks. Removal of vegetation can also increase flood risk. This is an example of an ENCORE dependency that can be difficult to interpret in financial terms given that it links to so many other of the dependencies outlined in ENCORE; including water supplies and water quality and flooding. This is why it comes out as such a high risk in the analysis (Box 3.1). Mediation of sensory impacts emerges as the third most significant risk. This service is also difficult to interpret in financial terms, but we interpret it here as a risk to labour productivity across sectors, and other costs, related to the impacts of biodiversity loss and environmental damage on human wellbeing. Hence, it comes out as a higher risk, because all sectors depend on labour. This form of financial risk has not been considered elsewhere so it is difficult to calibrate, however for comparison it is notable that the 2013 Chief Medical Officer's report estimated that the costs of mental health problems to the UK economy today are between £70 to 100 billion per year – 4.5% of gross domestic product (GDP).

	Agriculture	Construction	Electricity and utilities	Manu-facturing	Mining	Services	Transport	TOTAL	%GDP
Climate regulation	-5.5	-22.2	-7.6	-42.1	-7.2	-123.4	-27.1	-235.05	-10.22%
Dilution by atmosphere and ecosystems	-2.2	-4.7	-0.8	-37.9	-0.8	-27.8	-2.2	-76.52	-3.33%
Disease control	-2.4	-0.2	0.0	-1.1	-0.1	-2.0	0.0	-5.75	-0.25%
Fibres and other materials	-2.8	-0.3	-0.1	-3.4	-0.1	-8.8	-0.1	-15.61	-0.68%
Flood and storm protection	-0.6	-3.2	-1.5	-10.9	-0.6	-17.9	-3.3	-38.04	-1.65%
Genetic materials	-3.3	-0.6	-0.2	-8.4	-0.2	-8.0	-0.2	-20.92	-0.91%
Ground water	-4.2	-14.6	-6.5	-72.4	-4.8	-133.4	-13.3	-249.01	-10.83%
Mass stabilisation and erosion control	-1.3	-6.1	-3.2	-16.6	-1.7	-89.5	-4.8	-123.13	-5.35%
Mediation of sensory impacts	-1.7	-17.0	-2.4	-57.4	-1.1	-79.6	-8.0	-167.21	-7.27%
Pest control	-5.1	-6.6	-1.4	-3.2	-0.2	-9.1	-3.7	-29.26	-1.27%
--Pollination	-1.7	-0.2	0.0	-0.9	0.0	-1.8	0.0	-4.75	-0.21%
Soil quality	-4.5	-7.3	-1.5	-9.1	-0.4	-15.9	-2.3	-40.91	-1.78%
Surface water	-4.8	-16.5	-9.8	-82.7	-5.3	-163.5	-15.4	-297.97	-12.96%
Ventilation	-0.7	-2.8	-0.2	-8.7	-0.2	-8.2	-1.7	-22.56	-0.98%
Water quality	-2.2	-3.2	-2.9	-26.3	-1.4	-31.0	-4.1	-71.12	-3.09%

Figure 3.5: Annualised Value at Risk (roughly 1 in 100 year) by Sector and Ecosystem Service (grouped). Values in billions GBP. Shading represents severity. Direct + Indirect Risk.

The most significant financial risks, in monetary terms, are to the services sector, followed by the manufacturing sector (Figure 3.5). As noted above, it is not possible to combine risks across ecosystem services to calculate a total sector risk due to the double counting issues; however, the analysis suggests that the largest nature-related risks could constitute several percentage points of GDP (equivalent to around 13% of GDP for water-related risks alone). Services come out as greatest risk for two reasons. Firstly, the sector is so large in the UK, that even with a relatively small dependency on nature, the monetary value of that risk will be high. Secondly, the services sector is an 'aggregator' and so is exposed to risks faced by most of the rest of the economy, particularly via supply chains both domestically and internationally.

The highest risks as a proportion of economic output are to the agricultural sector, with the greatest risks associated with water, climate regulation, soil quality, pollution and pests (Figure 3.6). For climate regulation and regulation of quantity and quality of water, the proportional value at risk is 16% and 14%, respectively. However, there are also relatively high proportionate values at risk for the manufacturing sector and electricity and utilities related to water specifically. For electricity, this risk emerges as in the UK the electricity sector abstracts surface water for cooling power stations, and in an extreme scenario, constraints on water supplies could impact production at some facilities or increase the prices of energy and so impact demand.

	Agriculture	Construction	Electricity and utilities	Manufacturing	Mining	Services	Transport
Climate regulation	15.6	6.6	7.7	6.4	9.8	4.7	14.7
Dilution by atmosphere and ecosystems	6.3	1.4	0.8	5.8	1.1	1.0	1.2
Disease control	6.9	0.0	0.0	0.2	0.1	0.1	0.0
Fibres and other materials	8.0	0.1	0.1	0.5	0.1	0.3	0.1
Flood and storm protection	1.8	0.8	1.2	1.4	0.7	6.7	1.5
Genetic materials	9.6	0.2	0.2	1.3	0.3	0.3	0.1
Ground water	12.0	4.3	6.5	11.0	6.5	5.0	7.2
Mass stabilisation and erosion control	3.7	1.8	3.3	2.5	2.3	3.4	2.6
Mediation of sensory impacts	5.0	5.0	2.4	8.7	1.5	3.0	4.3
Pest control	14.6	2.0	1.4	0.5	0.3	0.3	2.0
Pollination	4.9	0.0	0.0	0.1	0.1	0.1	0.0
Soil quality	12.8	2.2	1.5	1.4	0.5	0.6	1.2
Surface water	13.8	4.9	10.0	12.5	7.1	6.2	8.4
Ventilation	2.1	0.8	0.2	1.3	0.3	0.3	0.9
Water quality	6.4	1.0	2.9	4.0	1.9	1.2	2.2

Figure 3.6: Percentage Value at Risk by Sector and Ecosystem Service (grouped)

	Agriculture	Construction	Electricity and utilities	Manufacturing	Mining	Services	Transport	TOTAL
Climate regulation	32%	46%	46%	62%	42%	67%	31%	58%
Dilution by atmosphere and ecosystems	33%	100%	96%	37%	100%	95%	44%	63%
Disease control	8%	100%	100%	100%	100%	100%	100%	62%
Fibres and other materials	8%	100%	38%	57%	100%	48%	100%	44%
Flood and storm protection	39%	59%	40%	42%	72%	63%	33%	53%
Genetic materials	13%	100%	100%	38%	100%	100%	100%	61%
Ground water	41%	81%	45%	43%	53%	58%	39%	53%
Mass stabilisation and erosion control	52%	67%	47%	62%	62%	53%	50%	54%
Mediation of sensory impacts	42%	56%	55%	34%	100%	52%	21%	45%
Pest control	9%	25%	8%	82%	100%	95%	9%	48%
Pollination	12%	100%	100%	100%	100%	100%	100%	69%
Soil quality	13%	29%	11%	45%	100%	90%	16%	54%
Surface water	40%	80%	38%	40%	52%	52%	37%	49%
Ventilation	23%	51%	92%	41%	100%	89%	20%	59%
Water quality	30%	100%	35%	37%	65%	75%	45%	57%

Figure 3.7: Indirect as total Output Impact/Total Output Impact. Blue indicates mainly direct impact and red indicates mainly (third-order) indirect impact. Cells with dark outlines also have a high %VaR (from Fig 3.4) and those with white text have VaR >50 billion GBP (Fig 3.3).

Importantly, we find that some of the largest risks to the UK overall are associated with international supply chains; indeed overall around half of all nature-related risks faced by the UK economy originate from overseas. The UK economy is strongly integrated with international supply chains and financial systems; this means economic strength but also exposure to nature-related risks around the world. For the first time, in this study, we are able to assess those risks, both in terms of their scale and origin (next sub-section). Figure 3.7 shows the balance of direct versus indirect (supply chain) risks for each sector and ecosystem service; blue indicates that the nVaR is more heavily driven by direct risks and red by indirect. Overlaid is information on the scale of the nVaR from Fig 3.3 and 3.4; high proportionate or absolute risk is shown by the bold outlines to cells (high absolute risk of greater than 50 billion GBP in white text additionally). The analysis shows that more than half of the significant risks to the UK services sector (including financial services) arise from supply chains. Given that a large part of the absolute nature-related risk to the UK comes through the services sector, this drives a large part of the overall vulnerability of the UK economy. Agricultural risk mainly arises domestically. Manufacturing faces both direct and indirect supply chain risks depending on the service.

3.3. Bank Portfolio nVaR

The Value at Risk varies significantly across the banks, but disruption to water provisioning stands out as a common threat to all the banks. The final part of the nVaR analysis analyses the nVaR in the context of the financial portfolios of seven banks, using the dataset described in Chapter 2.3. This is not a credit risk analysis or a stress test; it simply shows how the nVaR is allocated across banks given their portfolios. Figure 3.8 shows the nVaR for five sample ecosystem services as an example: water, pollination, ventilation (air pollution), soil quality and water quality. As explained in Box 3.1, it is not possible to sum up nVaR across services as they are not entirely independent, but this figure serves to allow comparation. Totals should also not be taken to imply a total risk to the bank as this figure shows only five of more than 20 ecosystem services studied. However, it is clear from this diagram that the patterns of exposure to different nature-related risks differs across the banks; with high exposure to water risks across the board, but two of the banks also facing non-negligible risks due to water quality in particular, but also ventilation and soil quality (banks 2 and 7). Banks with international portfolios tend to have different patterns of nature-related risks than the domestic banks.

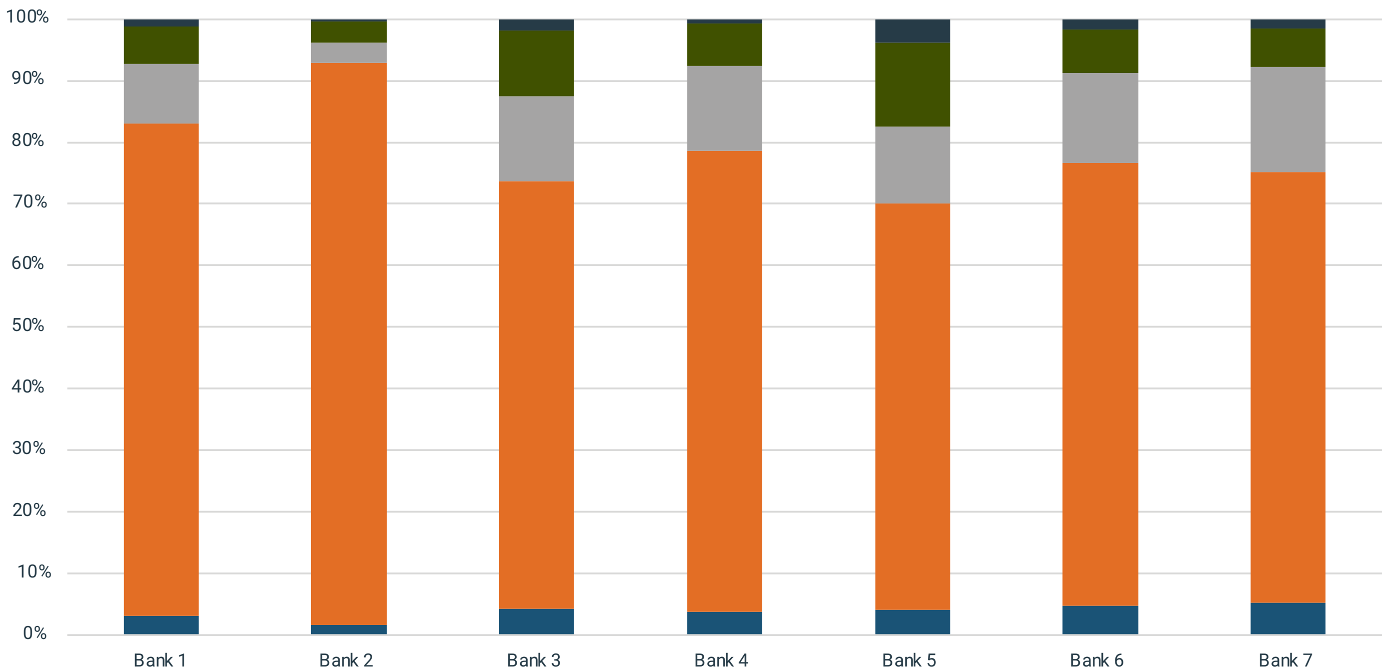


Figure 3.8: Approximate distribution of nVaR across banks for five example ecosystem services. Note that while the ecosystem services are stacked in this diagram, for reasons explained in Box 3.1, it is not possible to sum up across the services, so totals should not be overinterpreted.

Figures 3.9 and 3.10 show how the nature-related risks (in terms of nVaR) are distributed across regions and sectors. Note that these figures do not include the portfolio's holdings in the financial sector; this is the largest sector. This is because there is no information on what underlying sectors are being financed. Figure 3.9 shows that for most of the banks, the largest fraction of nVaR is coming from financing of UK firms. For two of the banks (bank 2 and 7), the largest share of nVaR is coming from the Asia-Pacific region (in purple), with a much small exposure to the UK (in pink). Three of the seven banks also include some nVaR from the United States (in brown). The share of the risk between regions varies significantly between ecosystem services. For example, for pollination (which has lower overall risk than the other three services), there is a much stronger exposure to Asia-Pacific. For soil quality and water quality, there largest exposes are to financing operations in Asia.

Figure 3.9: Portfolio-specific nVaR for seven banks, showing the distributions between regions.

For most of the banks, the level of portfolio nVaR is well over on two billion euros, and in one case it is well over 8 billion euros, from water-related risks alone. Figure 3.10 shows the distribution of risks across sectors for the seven banks for four ecosystem services (see also Box 3.2). When finance is removed, Fig. 3.10 reveals the large water-related risks to construction (real-estate). Water quality and soil quality risks are dominated by manufacturing. Pollination risks are dominated by agriculture, but also can be seen in manufacturing (e.g. food products).

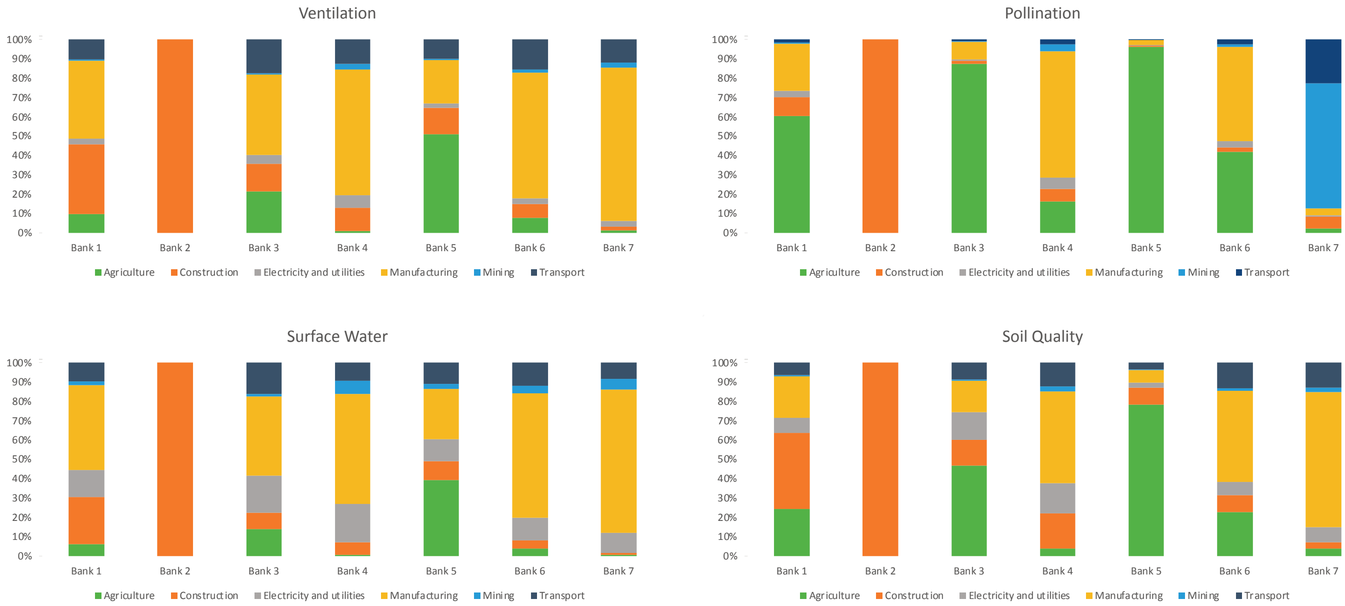


Figure 3.10: Portfolio-specific nVaR for seven banks, showing the distributions between sectors.

Box 3.2: NACE Codes

A - Agriculture, forestry and fishing
B - Mining and quarrying
C - Manufacturing
D - Electricity, gas, steam and air conditioning supply
E - Water supply; sewerage; waste managment and remediation activities
F - Construction
G - Wholesale and retail trade; repair of motor vehicles and motorcycles
H - Transporting and storage
I - Accommodation and food service activities
J - Information and communication
K - Financial and insurance activities
L - Real estate activities
M - Professional, scientific and technical activities
N - Administrative and support service activities
O - Public administration and defence; compulsory social security
P - Education
Q - Human health and social work activities
R - Arts, entertainment and recreation
S - Other services activities
T - Activities of households as employers
U - Activities of extraterritorial organisations

Part B: Scenario-Based Analysis

Assessing Nature-Related Risks to the UK Economy and Finance

Chapter 4. Nature-Related Risk Scenarios

Authors: Nicola Ranger, Jimena Alvarez, Tom Oliver, Anne Verhoef, Mike Perring

4.1. Introduction

Scenario analysis is a common tool for risk management by financial institutions that is required by financial institutions across most jurisdictions. It is a go-to tool for assessing and managing a wide range of risks, predominantly macroeconomic risks, but also physical climate shocks (for insurance), and recently long-term stresses and exogenous shocks like climate change.

Scenario analysis for climate change is still relatively new, and it is even more nascent for nature. Some Central Banks are completing bottom-up climate scenario analysis exercises (i.e. where they provide scenarios and ask firms to complete the exercise and report back) or top-down (i.e. where the Central Bank itself does the analysis based upon data on the exposures of individual financial firms). As introduced in earlier Chapters, the UK, for example, conducted its first 'bottom up' climate scenario exercise (the CBES) in 2021-2022. More than 30 Central Banks and supervisors have completed or have in progress climate scenario analyses.

Most of the climate scenarios used by Central Banks to date have been based on those developed by the NGFS. These global scenarios are often applied with some modifications to meet the needs of specific jurisdictions. The NGFS is on its fourth iteration of scenarios and each iteration has come with substantial improvements. However, several authors have pointed out challenges with the NGFS scenarios (Ranger et al. 2022 and Trust et al. 2024), including a poor representation of shocks and tail-risks and an over-reliance on integrated assessment models that are known not to capture many forms of climate risk. As outlined in the Introduction, given the complex nature of nature-related risks, scenarios must address the need to represent shocks and tail-risks head-on and this is the approach taken in this project.

4.2. Our approach

To understand nature-related risks to finance, one approach is to use Integrated Assessment Models (IAMs). IAMs include simplified representations of the Earth and human systems, and their interactions, to assist policy-making (UNFCCC, 2023). This is the approach adopted to generate the NGFS climate scenarios to date and has been used in some previous studies that help quantify nature-related for particular sectors or services (Ceglar et al. 2024; Johnson et al. 2023). However, it is well known that the use of these scenarios for the case of climate change leads to significant underestimations of risk. It is important to explore new approaches that try to avoid this as we begin to develop nature scenarios. Nature-related risks to financial systems operate through many complex and indirect transmission channels that are not captured through current IAMs (Ranger et al. 2022). From Figure 4.1, IAMs will not capture many of the key risk transmission channels, such as the links between vegetation removal, wildfires and pollution, the links between agriculture, biofuels, oil and fiscal resilience, and in particular the complex interactions across sectors and scales. The importance of these is clearly demonstrated through the history of ecological shocks (Ranger et al. 2023) as well as through lessons from the Global Financial Crisis and recent crises such as the invasion of Ukraine.

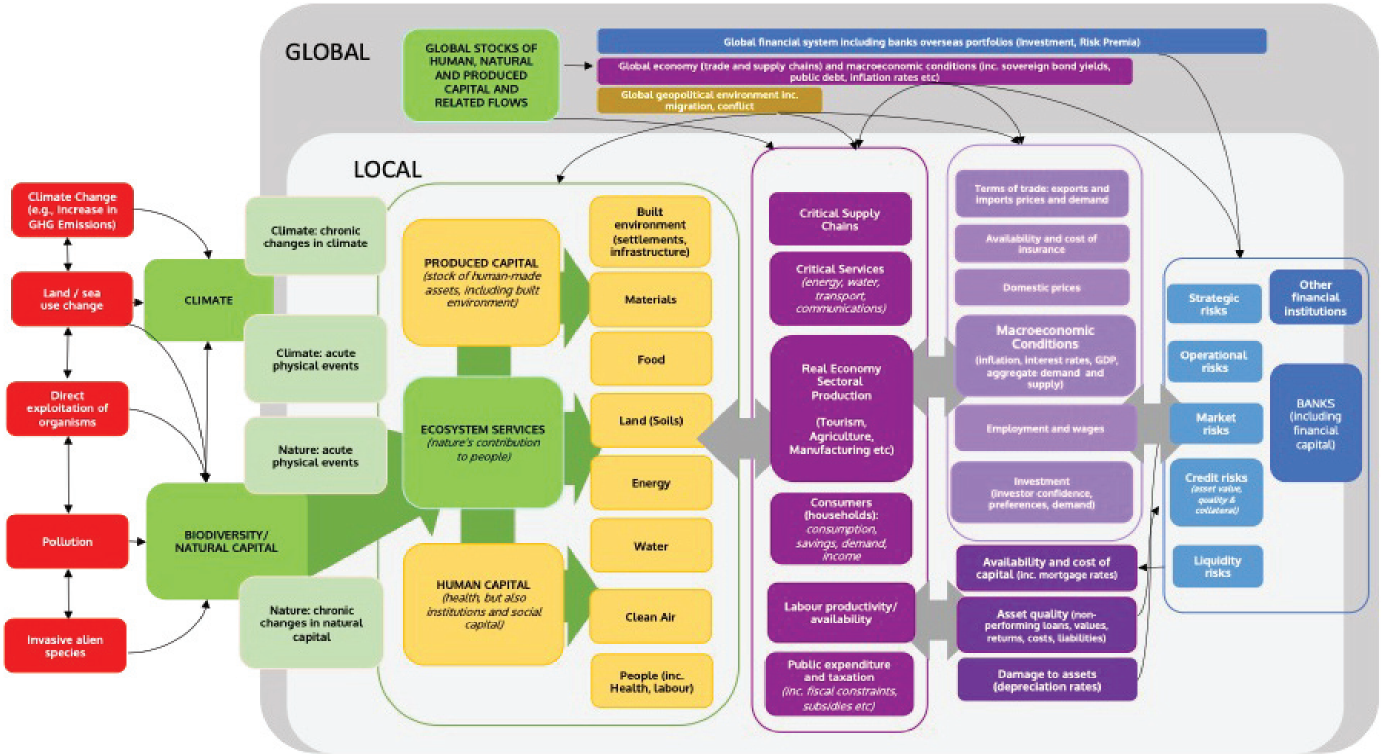


Figure 4.1: Risk transmission channels between nature and finance. Source: Ranger et al. 2023

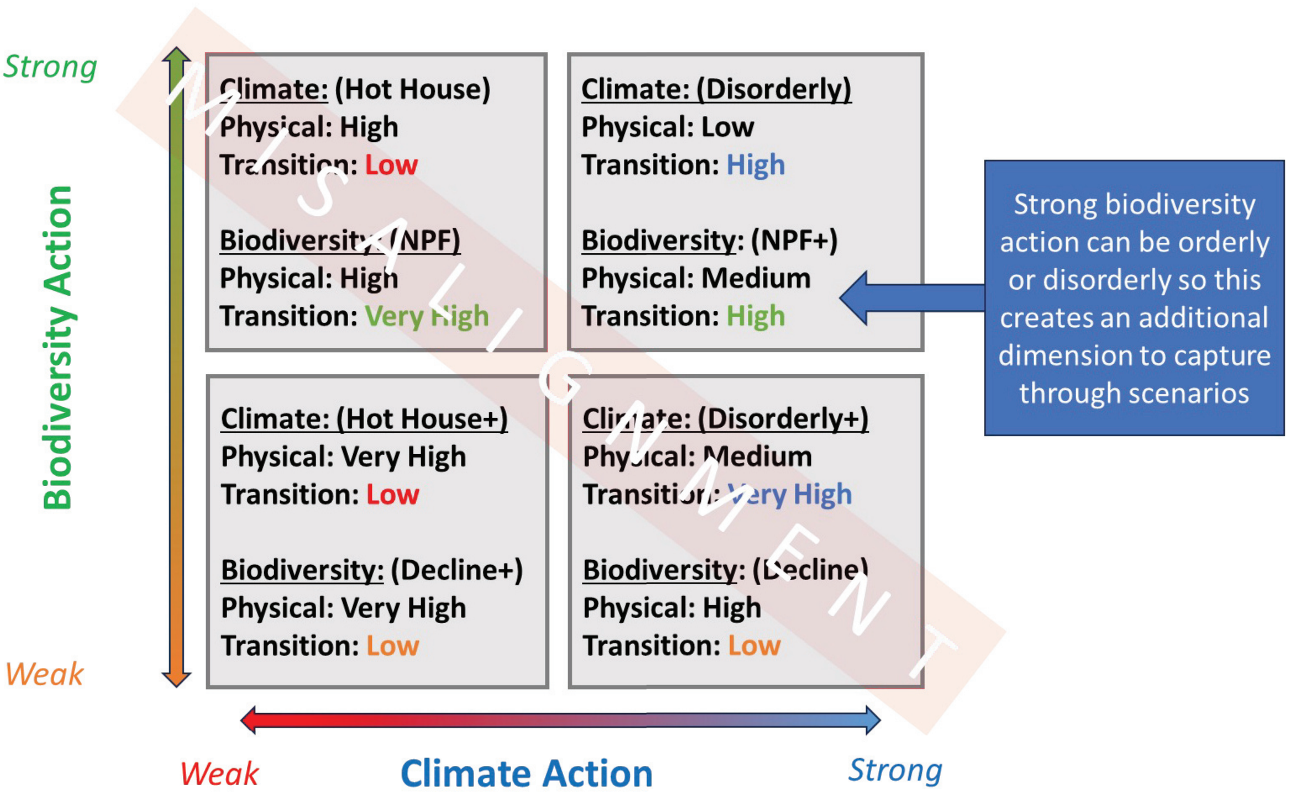


Figure 4.2: The INCAF Scenario Framework. Source: Ranger et al. 2023

To develop an approach to design scenarios relevant for macro-prudential and micro-prudential policymaking on nature-related risks, our approach was to first revisit the literature on scenario design for other forms of risk to the financial sector. Our central design principle is consistent with IMF (2019): scenarios for bank stress testing should be "forward-looking, severe, consistent, and robust trajectories for a comprehensive set of macro-financial variables that react following the materialization of shocks… Scenario design starts with a narrative about how the realization of tail risks could interact with financial vulnerabilities to generate severe but plausible macro-financial impact". This focus on generating severe but plausible scenarios is also consistent with other regulatory frameworks. For example, according to the European Banking Association (2019) guidance (recommended by the ECB), the design of the stress test scenarios should not only be based on historical events, but should also consider hypothetical scenarios based on non-historical events (in particular non-analogue climate conditions from those in which the modern financial system has evolved). Institutions should ensure that scenario designs are forward-looking and take into account systematic and institution specific changes in the present and foreseeable future. IFRS 9 requires firms to use multiple scenarios to produce probability-weighted lifetime expected credit losses. Under Solvency II, capital requirements are determined on the basis of a 99.5% VaR (1 in 200) measure over one year, meaning that enough capital must be held to cover the market-consistent losses that may occur over the next year with a confidence level of 99.5%, resulting from changes in market values of assets held by insurers. Under Basel III, the minimum capital adequacy ratio that banks must maintain is 8%. The capital adequacy ratio measures a bank's capital in relation to its risk-weighted assets. Under Basel III, Common Equity Tier 1 must be at least 4.5% of risk-weighted assets (RWA) while Tier 1 capital must be at least 6% and total capital must be at least 8.0%. These regulatory requirements again highlight the importance of forward-looking scenarios and assessing tail-risks, e.g. potential evidence in the range 1-in-15 to 1-in-200 likelihood of occurrence.

Based upon this literature review on current regulatory and supervisory practices, we therefore conclude that it is important to develop an analytical framework for scenarios which can capture the 'bigger picture' of risk transmission, to understand the plausible but severe potential risks that could emerge related to the loss of biodiversity and ecosystem services, including the feedbacks and dependencies between climate change and nature (captured in our proposed scenario framework, Fig 4.2 described in detail in Ranger et al. 2023). A narrative scenario approach is also consistent with that proposed in the guidance of the TNFD (TNFD 2023). A previous systems thinker, Frederic Vester, who produced seminal work in cybernetics, gave an example that if we seek to understand flow of traffic in a city it would not be sensible to focus on just one city district in highly precise quantitative detail and ignore other parts completely (Vester, 2007). It would be better to gain a coarser, but more comprehensive, understanding of the larger system and ultimately use this to inform on the design of a quantitative model. There have been suggestions from leading climate scientists, that a similar approach needs to be taken in climate and environmental impact analysis, i.e. beyond IAMs towards more 'storyline analyses' (Shepherd, 2019; Arribas et al. 2022[16]). These more qualitative approaches can better capture 'systemic risks' (i.e. cascading risks across socio-ecological systems influenced by political, economic, social, and technological context; Sillman et al. 2022). As economists John Kay and Mervyn King suggest in their book Radical Uncertainty (Kay & King, 2020) "Good decisions stem from using non-quantitative information combined with experience and learning from others". These qualitative scenarios are then used to generate quantitative scenarios by drawing together multiples lines of evidence including modelling.

[16] Also see RECEIPT, a project trying to apply storyline thinking to systemic risk to Europe arising from climate change outside of Europe.

In essence, IAMs and narrative or storyline approaches sit at opposite ends of a spectrum between precision and robustness and our approach is to combine the best elements of both to achieve both robustness but also to provide the quantitative information required by financial institutions (Figure 4.3). Specifically, our approach is to use narrative scenarios to explore the full space of possible outcomes related to biodiversity loss and environmental degradation, and use this understanding to then select multiple model approaches to quantify as many aspects of those scenarios that is possible given the toolkit available (Figure 4.4).

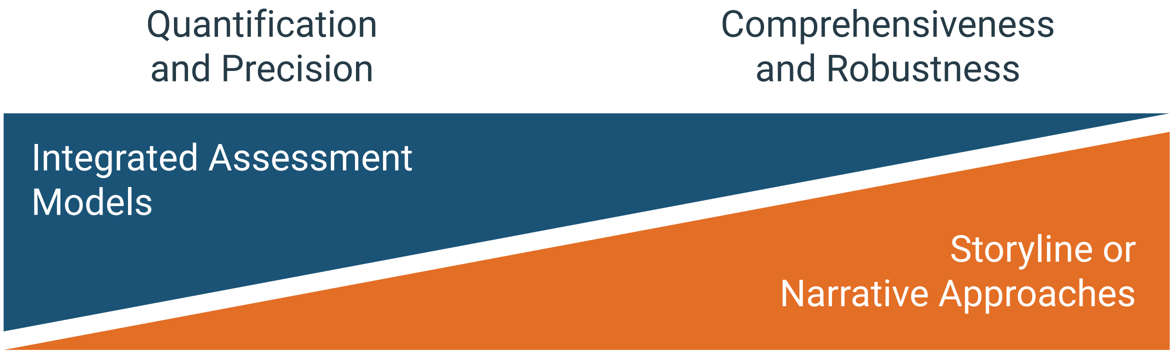


Figure 4.3: Illustration of the trade-off in robustness versus precision/quantification inherent in the selection of IAM-based assessment versus narrative/storyline approaches

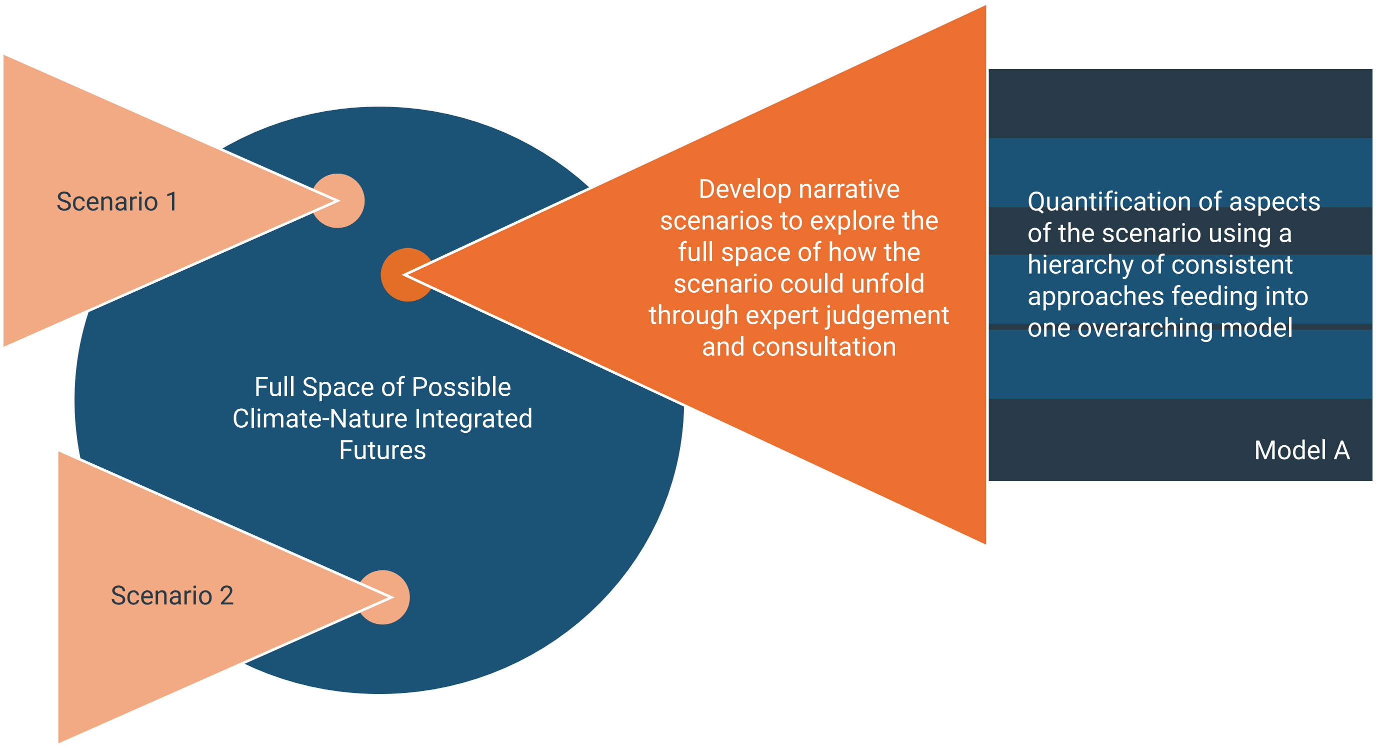


Figure 4.4: Illustration of our approach to use narrative scenarios to explore future outcomes in a comprehensive way, combined with models and the approaches used to quantify as much of the scenario as possible robustly with the toolkit. In our approach, all the quantitative scenario data is fed into the NiGEM

model to assess the macroeconomic impacts.
In this Chapter, we develop the storylines to explore how various nature-related risks emerge and interact to create disruption to economic and financial systems. Each of these scenarios can include compounding effects of multiple interacting risks (see Chapter 1 UK-NRRI). The following Chapter then develops quantitative scenarios based on these storylines.

4.3. Methodology

From our literature review and discussion with project stakeholders, we identified several key criteria for scenario development:

- Plausible yet extreme in terms of potential material financial impact
- Include multiple nature-related risks that likely co-occur through a shared driver or feedback processes (i.e. avoiding siloed analysis of single risks)
- Impact financial systems in unexpected ways, i.e. where central banks and supervisors may be overlooking such risks and they are not covered in CBES assessments
- Include elements of both transition and physical risks
- Create diversity across the three scenarios, so that the financial system can be stress tested in different ways (i.e. diversity in risk transmission channels across scenarios)

All scenarios take place in the "Too Little, Too Late" scenario world (Figure 4.2), where global mean temperatures are expected to rise by around 2°C by 2050, compared to pre-industrial, and action to protect and restore biodiversity and natural capital follows current policies. This is suitable given the stress testing nature of this study, but future work will expand to other quadrants. In this scenario world, despite the agreement on the Global Biodiversity Framework, progress on protection and restoration is slowed across many countries globally by a continued failure to address the key underlying socioeconomic drivers of the erosion of natural capital and biodiversity, and/or the aggravating effect of climate change on the ecosystem services (ES) they provide. Physical risks from climate change and biodiversity are very high whilst transition risks are low. The scenarios were developed as part of the Integrating Nature-Climate Scenarios & Analytics for Financial Decision-Making (INCAF) project and are based upon expert consultations and literature reviews conducted over more than eight months during 2023/24.

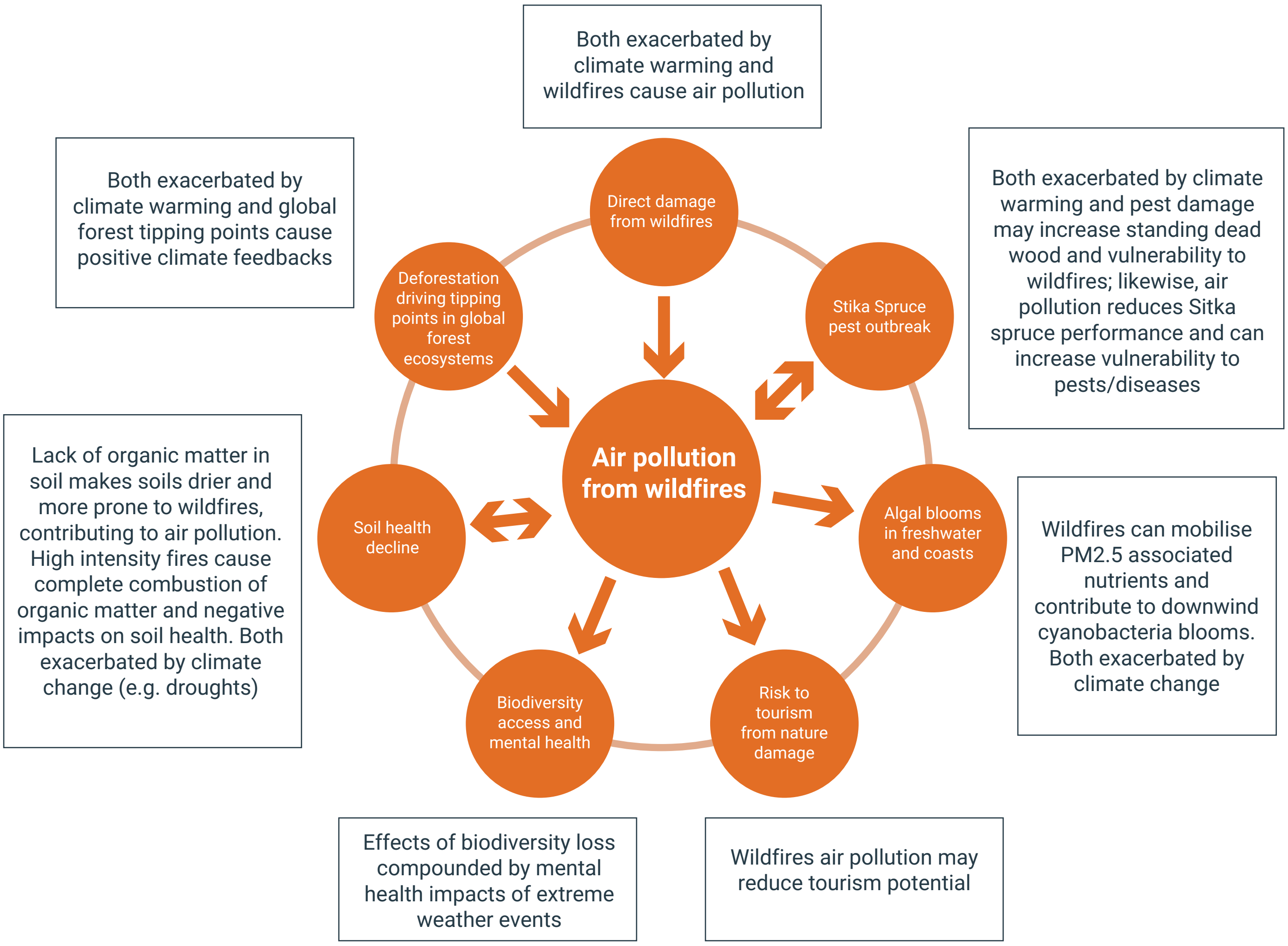


Figure 4.5: Example of the focal risk of air pollution from wildfires with associated risks in NRRI and how this is used to identify co-occurring risks to build scenarios. Arrows into the focal risk are interactions where the secondary risk increases the likelihood or impact of the core risk, arrows outward are where the focal risk exacerbates the secondary risk, and arrows in both directions show bi-directional effects.

The individual scenarios are identified and developed based upon the 'long-list' of individual nature-related risks from the UK-NRRI (Section 1). Consultations were conducted with 25 experts to understand the associations between the NRRI risks and assess the concurrence between risks in terms of the likelihood they may occur at the same time. For example, two risks may be likely to happen at the same time as they emerge through shared drivers, or there may be feedback effects where one risk makes another more likely or unlikely (Figure 4.5 for air pollution and wildfire example). For example, wildfires, freshwater pollution and algal blooms in freshwater and coastal areas are all exacerbated by climate warming (shared driver). There are also direct interactions, for example wildfires can cause freshwater pollution as a function of suspended particulate matter (SPM from burned Cr-rich Ferralsols soils[17] (Thery et al, 2023), while wildfires can mobilise PM2.5[18]-associated nutrients and contribute to downwind cyanobacteria blooms (Olsen et al, 2023). The analysis of concurrence between risks enables the identification of clusters of interrelated risks, which can be developed into compounding scenarios (Figure 4.6). For any focal risk selected from the UK-NRRI, the concurrent risks table can be used to identify associated risks and build scenarios. In this project, this analysis was then used with stakeholders to iteratively co-develop the scenarios.

[17] Cr-rich: chromium rich; "Ferralsols are very highly weathered soils that are found primarily in the intertropical regions of the world" (Kögel-Knabner & Amelung, 2014).
[18] PM2.5= particulate matter of less than 2.5 micrometres in diameter (DEFRA, 2023g)

Figure 4.6: Summary of the process used to develop scenarios

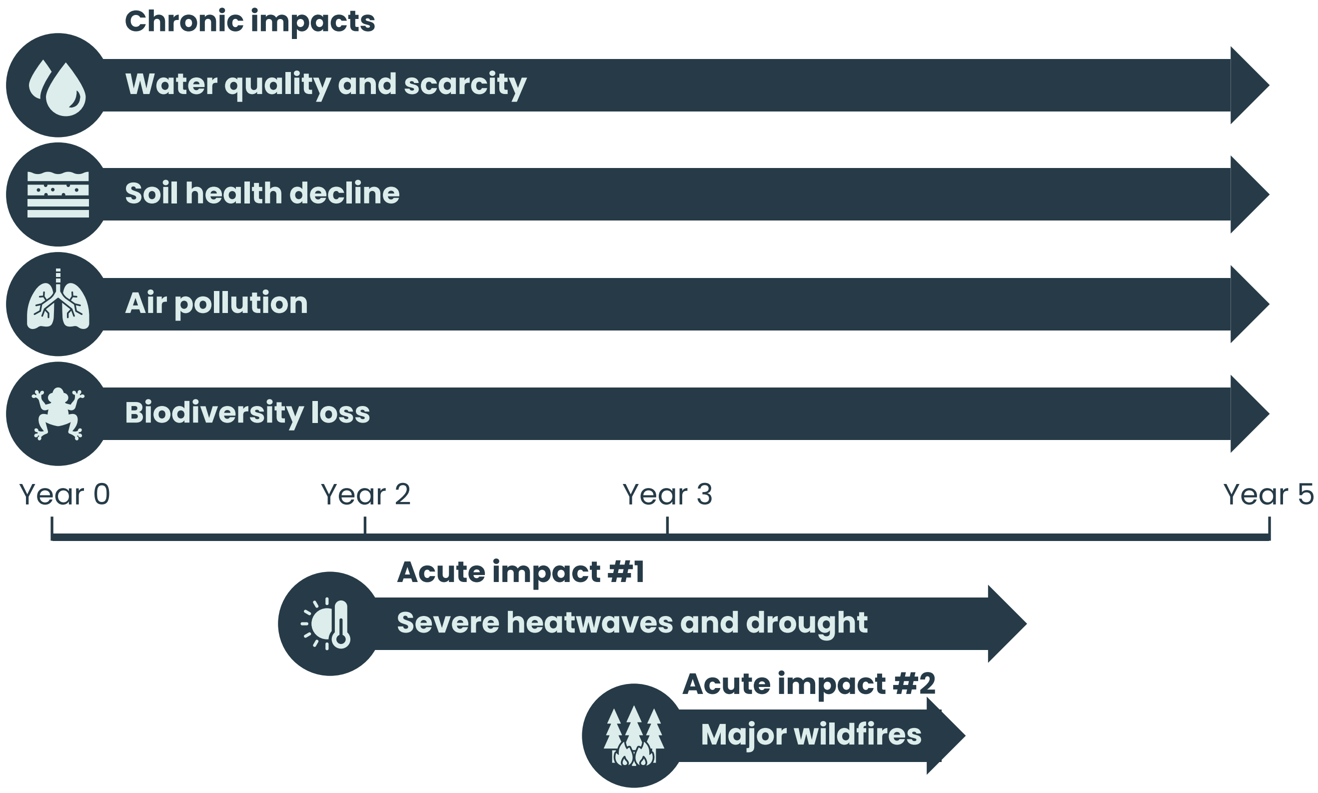
Scenarios were then simplified (or 'pruned') to make them sufficiently targeted for financial risk analysis in collaboration with NIESR (Figure 4.6). Three scenarios were finally selected in collaboration with the project stakeholders. Each scenario shares a common structure:

- Scenarios specified over 2023 – 2050, with a 10-year window of interest between 2025-2035 for the financial scenario analysis application.
- Up to 4 chronic impacts that run continuously from 2023-2050
- Two acute impacts that occur in the centre of the window of interest ~2030 and are designed to represent an event with (very roughly) around 1 in 100 annual probability.

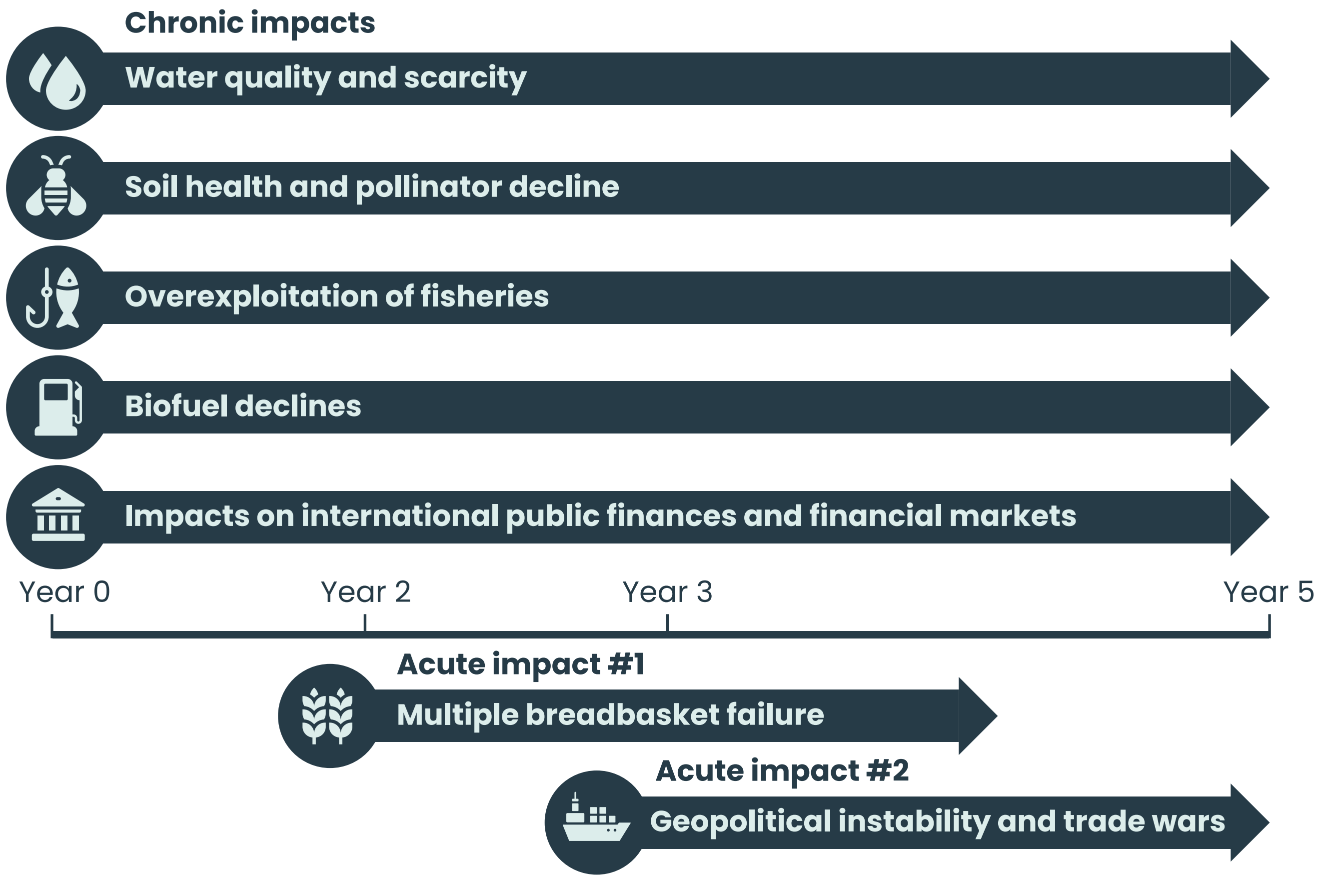
The project used relatively near-term scenarios based upon feedback from financial institution stakeholders. This aims to match the scenarios as closely as possible with the time periods used by financial institutions within their internal risk management. A trade-off of this is that it does not allow the study to explore more extreme outcomes associated with longer time periods (e.g. 2050) but these will be a focus of future research in Phase II. For transmission pathways that could not be fully captured in NiGEM, we conducted a qualitative analysis of these 'systemic risk dimensions' (see Annex 7)

Figure 4.7 shows the three scenarios following the scenario pruning exercise with NIESR and the full narrative scenarios are described in detail below, with a significant amount of further information and analysis available in Annexes 4, 5, 6 & 7. This includes a detailed literature review of the evidence base associated with each component of the scenario, which is used in the quantification process in Chapter 5.

DOMESTIC SCENARIO



INTERNATIONAL (SUPPLY CHAIN) SCENARIO



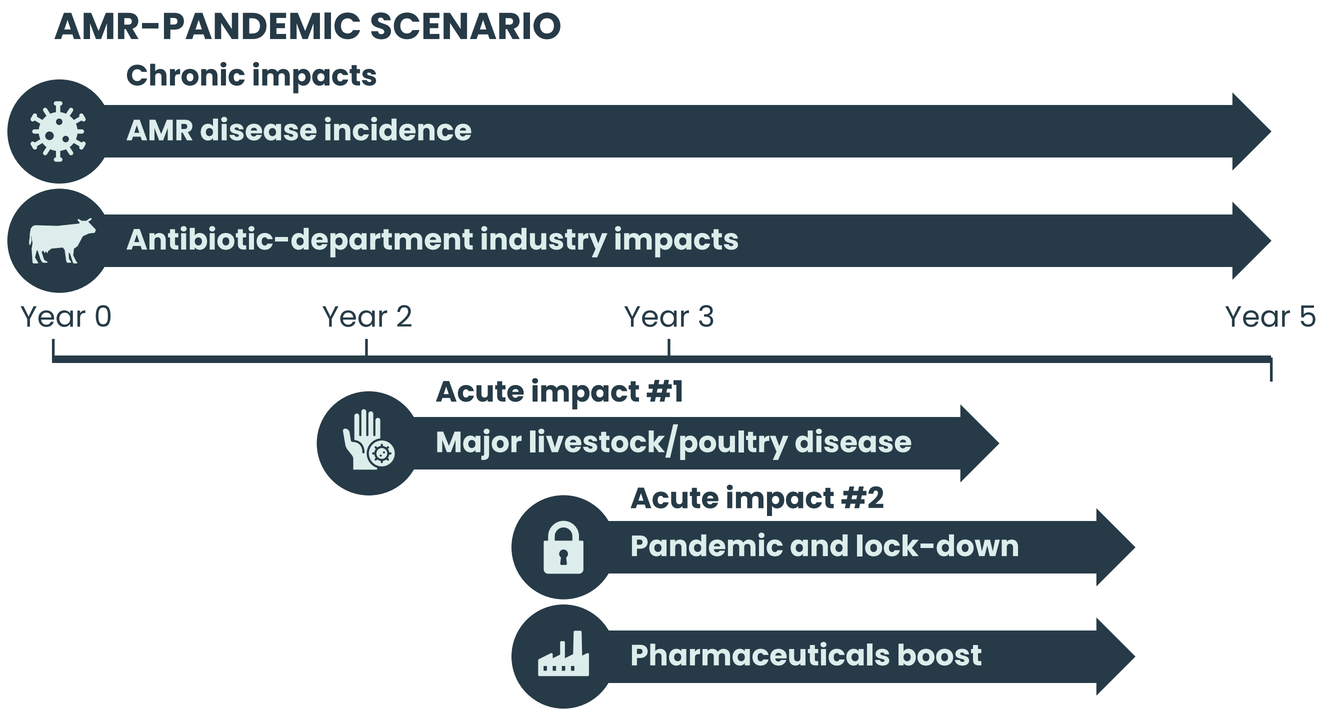


Figure 4.7: Summary of the three physical-risk scenarios modelled

4.4. Domestic scenario

Overview: risk storyline
The UK Domestic scenario includes two components: chronic and acute. Firstly, chronic impacts under this scenario result from a long-term baseline decline in environmental quality including water quality and quantity, soil health, air quality and biodiversity loss in the UK. Secondly, in 2030, an acute event of extended heatwaves and droughts further exacerbates health impacts from air pollution, reduces agricultural productivity and water availability in the UK. Thirdly, in 2031, an acute event of major wildfires occurs in the UK leading to major impacts on air pollution, disruption of transport and capital damage. The scenario is illustrated in figure 4.8. See Annex 4 for the evidence.

Chronic component:
- **Water pollution and water scarcity:** Bridging the gap between the high level of water pollution and the commitment set out in the Water Framework Directive requirement as well as increasing pressures on water security results in large investments in water quality and security improvements. These costs are transferred to users, increasing household and industry costs. Despite the investments, physical risks from water pollution and scarcity remain, given the uncertainty and complexity in achieving restoration of polluted waters and depleted water resources.
- **Soil health decline:** Gradual soil degradation (including erosion, compaction, nutrient and biodiversity loss) leads to reduced yields, particularly affecting highly productive regions in the UK (e.g. East Anglia). Damage to agriculture from soil health, biodiversity loss and drought cause the collapse of agricultural SMEs and exposure for particular lenders.
- **Air pollution:** The increasing threat from air pollution negatively impacts human health and, in turn, increases pressure on the NHS whilst increasing public health expenditure and decreasing labour availability and productivity.
- **Biodiversity loss:** In addition, biodiversity loss negatively affects access to green spaces and increases mental health issues (anxiety, depression).

Acute component:
An acute shock of severe heatwaves and drought in 2030, compounds with the existing chronic impacts on soils and water and leads to severely reduced crop yields in the UK and Northern Europe negatively impacting agriculture Gross Value Added (GVA) and the food sector. Water supplies are impacted, with emergency measures (tankers) taken to ensure water supply across users (e.g. households, industry, agriculture) causing increased public expenditure and water costs. In addition, heat impacts of prolonged heatwaves on major cities further exacerbate chronic health impacts as well as reduce overall productivity and labour productivity. Localised but extensive wildfires in 2031 results in capital damage in affected areas, in addition to air pollution impacts beyond the focal fire points and disruption of transport. Acute air pollution impacts from heatwave and wildfires causes overwhelm of NHS capacity, worse health outcomes and more severe impacts on labour availability, as well as increased public expenditure on health.

DOMESTIC SCENARIO

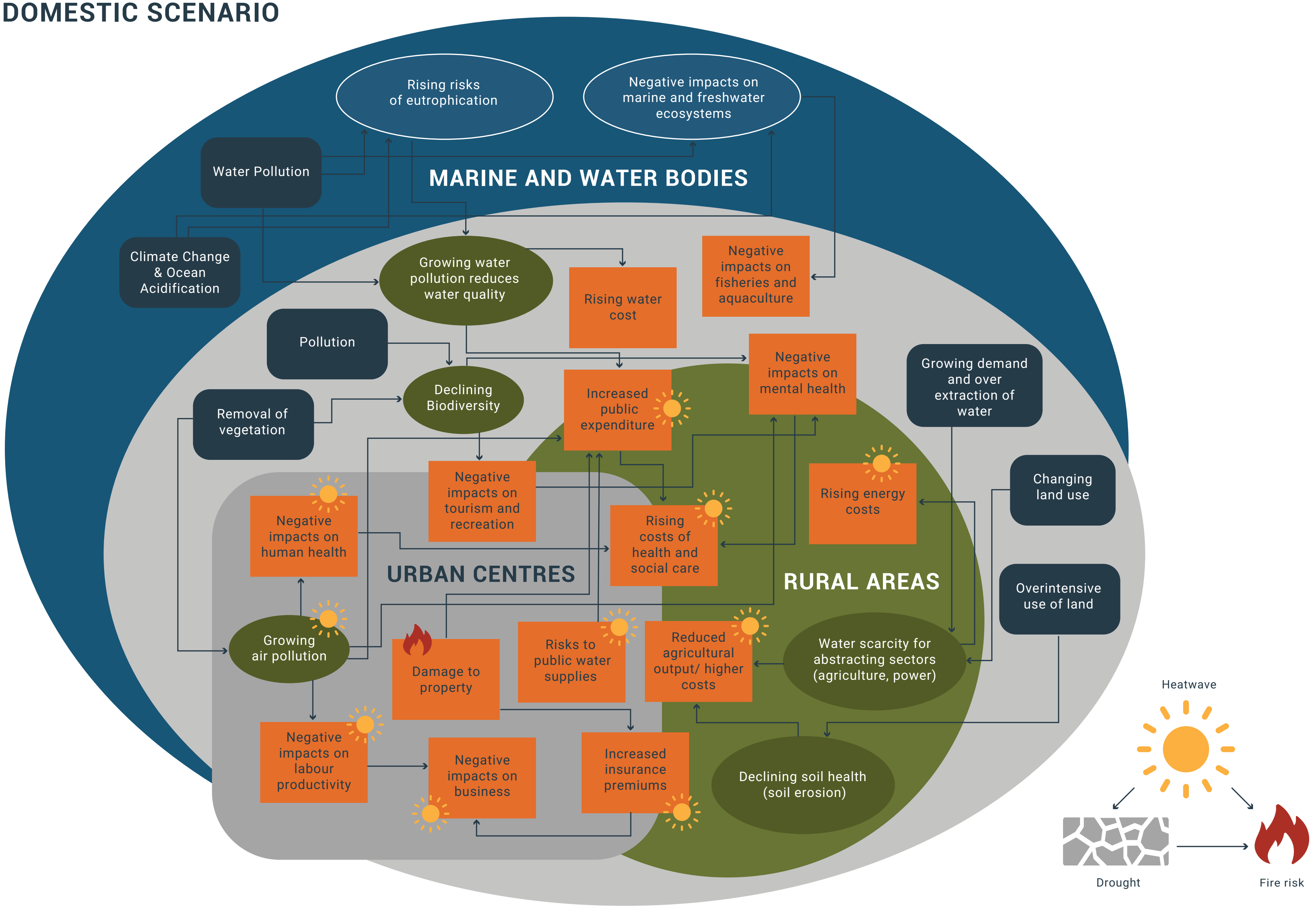


Figure 4.8: Graphic representation of the domestic scenario

4.5. International (supply chain) scenario

Overview

The International (supply chain) Scenario includes two components. Firstly, a chronic component, including continued stresses to ecological systems across many countries, impacting on key ecosystem services. Secondly, an acute component, taking the form of a strong El Niño, causing reductions in precipitation across many food and natural commodity producing regions, with impacts compounded by ongoing soil erosion, deforestation and overextraction of water. These combined effects lead to significant loss of crop production for some of the largest agricultural regions of the world – a 'multi-breadbasket failure' as well as impacts on other key commodity supply chains (biofuels, fruits) - and knock-on impacts for global commodity prices and the financial system. This is a multi-dimensional scenario that tries to capture the reality of the complexities of multiple drivers acting at different scales at the same time with global macroeconomic impacts (Figure 4.9)[19].

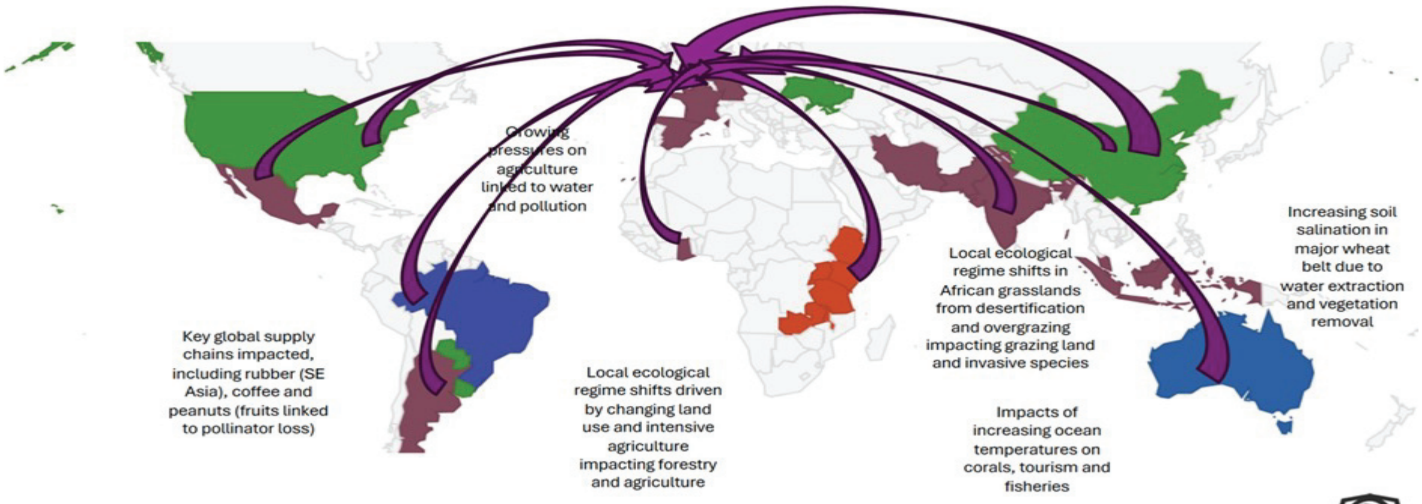


Figure 4.9: Sources of UK risk by broad geographic region in the international scenario.

Chronic Component:

- **African Region:** Ecological regime change in African grasslands, resulting from desertification, climate change and overgrazing, leading to a loss of grazing land and increased risk of invasive plant species. Agricultural output may be increasingly threatened by over-intensive use of soils and compounded by climate change. Concurrently, parts of Africa suffer from increasing risk of water scarcity due to a combination of overextraction of water from rivers and groundwater, and climate change. Rising pollution, including that of air, land and water, leads to increased health risks for people and livestock and threatens pollinators. When combined with rising risks of agricultural pests and diseases, this contributes to further reduction in agricultural outputs. Reduced productivity of commodities sectors and rising costs of water and raw materials could increase financial and fiscal risks.
- **Amazonian Region:** Overexploitation of land, and climate change, lead to gradual regime shift of forestry in the Amazon, with significant impacts on people and key supply chains, for example food, timber, animal feeds (e.g. soya) and meat. Changing water availability could also increase prices to energy and manufacturing sector. Environmental pollution aggravates these impacts, affecting people, pollinators and animals. Gradual increase in soil degradation (due to salinisation, compaction, wind erosion, biodiversity loss, and loss of nutrients) coupled with decline in pollinators results in lower yields.

[19] We note that while the scenario is based on a strong evidence base, it is only one of many scenarios that could have been developed. The fact that some risks are not included, should not be interpreted as those risks being not important and vice versa.

- **Asia-Pacific (APAC) Region:** Across South and Southeast Asia, increased risk of invasive species and pest attacks have a sizeable impact on concentrated supply chains causing global shortages in core products (e.g. rubber, coffee, peanuts, bananas), and so rising prices (temporarily). In Southwest Australia, increasing soil salination in this major wheat belt caused by over-extraction of water and vegetation removal lead to reductions in cereals.
- **Europe and USA:** Droughts and heatwaves, aggravate existing pressures on water systems leading to increased water and energy prices. Pollution, while declining locally, continues to lead to health issues for people, pollinators and animals. Diversifying import sources to improve food security, and applying minimum sustainability criteria, increases operating costs for retailers and lead to price rises.
- **Oceans and water bodies:** Overexploitation of fisheries coupled with nutrient pollution and invasive species affecting aquaculture results in a partial collapse of the fisheries increasing prices. Increased eutrophication leads to localised water supply issues and health risks.
- **Global Impacts:** These growing chronic impacts across the world lead to increased pressure on global commodities markets and key supplies of manufactured goods and consequently increased volatility and uncertainties in prices and production. Finite land availability and increasing food insecurity leads to reversal of biofuel mandates as growth of biofuel crops competes with food production, putting an upward pressure on oil prices. The combined effects have significant impacts on the global financial system, with rising risk premia on transactions, growing debt sustainability challenges in parts of the world. Growing fiscal issues and financial sector vulnerabilities globally, increase risk of financial instability, particularly in emerging and developing economies. Land degradation, pollinator loss and fertiliser price increases contribute to soil health degradation, disruption of cereal and fruit/veg production, exacerbating food insecurity.

Acute Component:
The chronic situation is aggravated by a strong El niño shock, with impacts on agricultural production and flooding across countries . In year 2, pesticide resistance and invasive species coupled with chronic soil degradation, pollination loss and drought result in multiple breadbasket failure, as well as significant impacts in several key global commodities supply chains. As a result, food prices increase considerably, production and consumption costs in particular, and food insecurity increases (exacerbating the 'cost of living crisis' in the UK). Spikes in food prices increase food insecurity which, coupled with poor governance, lead to civil unrest. Knock-on effects from the multiple breadbasket failure coupled with deliberate limit of supplies of critical resources (e.g. minerals) for geopolitical gain results in shortages which escalate trade restrictions and lead to localised civil unrest as well as trade wars in year 3.

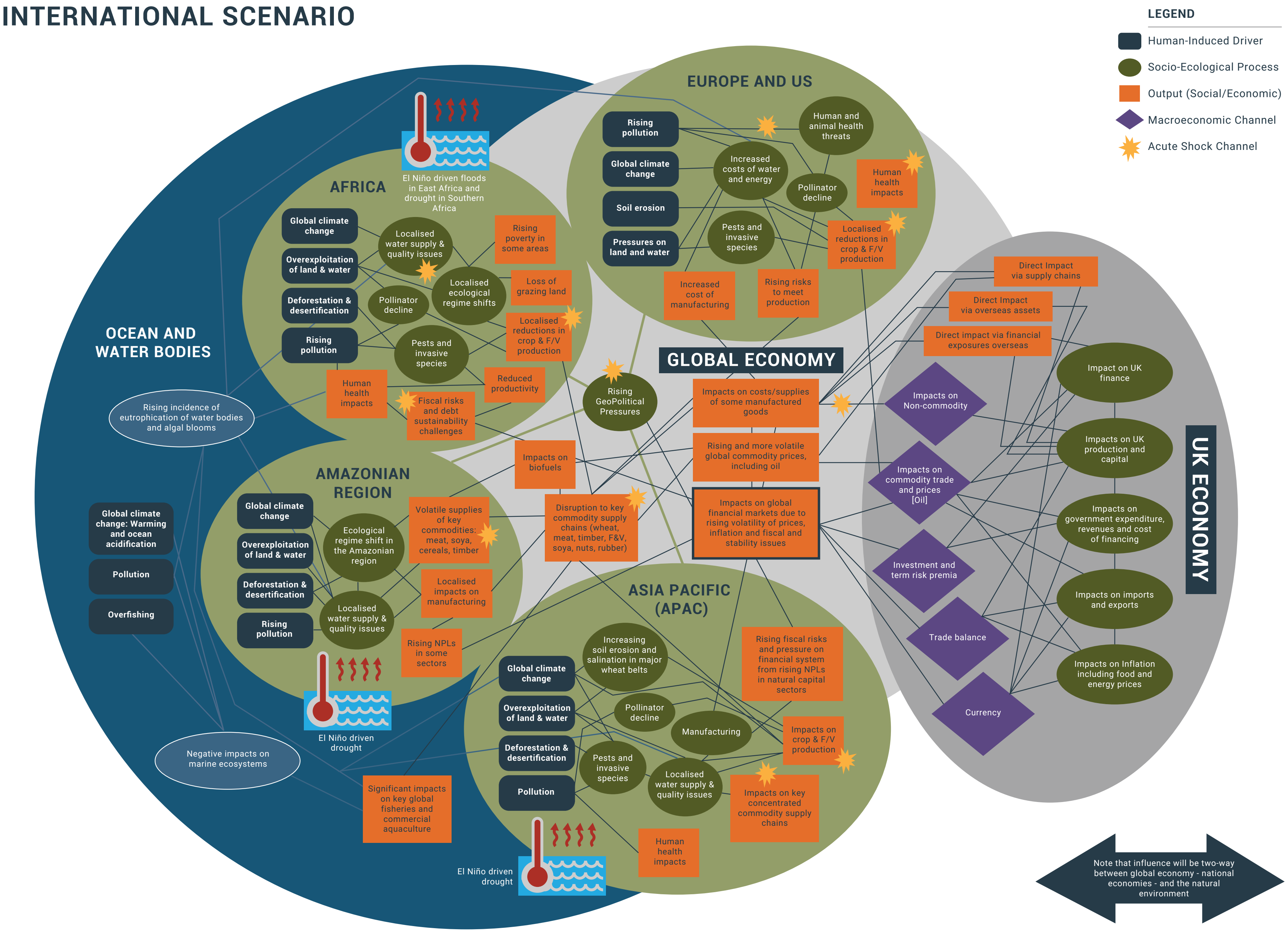


Figure 4.10: Graphic representation of the International (supply chain) scenario

4.6. Health (AMR-Pandemic) scenario

Overview: Risk storyline

This scenario relates to the spread of anti-microbial resistance (AMR) in the environment combined with livestock disease and a zoonotic disease pandemic. Like the Domestic and International Scenarios, the AMR-Pandemic Scenario includes two components. Firstly, a chronic component, including a rise in AMR leading to a global increase in infectious diseases which spread more easily and are more difficult to treat, resulting in significant increases in morbidity and fatalities. This is accompanied by widespread antibiotic-dependent industry impacts, primarily affecting the agricultural sector, which is globally reliant on antibiotics through their use in intensive livestock farming, in addition to broader economic impacts such as a decline in labour availability and productivity (with a concomitant impact on global trade) and increased public health expenditure. Secondly, an acute component, taking the form of the emergence of a major disease which causes a reduction in poultry and livestock production (accompanied by the widespread collapse of agricultural SMEs), which then transfers into human populations, causing a global human pandemic on a similar scale or greater to that of Covid-19, with comparable economic impacts and a slower pace of recovery due to compounded effects (albeit a boost to certain sectors such as the pharmaceutical industry).

Chronic Component:

- **AMR mortality/morbidity.** AMR is caused by the overuse and misuse of antimicrobials, including antibiotics, antiseptics and antifungal agents, which results in mutations in the microorganisms which cause diseases; they become resistant, resulting in infectious diseases which are more difficult to treat and easier to spread, resulting in high rates of mortality and morbidity. AMR is on the rise; by 2030, the global human consumption of antibiotics is forecast to rise by more than 30%, at the current rate rising up to 200%. It is estimated that by 2050 AMR could directly and indirectly be responsible for up to 10 million deaths per year globally if strong and effective action is not taken.
- **Public health expenditure.** An increase in AMR-related mortality and morbidity puts a substantial pressure on the healthcare system through increased and prolonged admissions and the costs of medication. In the UK, AMR costs the NHS £180 million every year. Worldwide, it is projected that AMR could cost from $300 billion to more than $1 trillion annually by 2050.
- **Economic impacts.** An increase in AMR has severe global and national economic consequences as it causes increased mortality and morbidity, with knock-on effects of a decline in labour productivity, GDP, household income and tax revenues, and a rise in unemployment and inflation. In addition, global exports could decrease significantly by 2050 due to the effects of antimicrobial resistance on labour-intensive sectors; a high AMR-impact scenario is projected to result in an almost 4% annual decrease in global GDP. As well as environmental restoration policy within the UK, transition risks could include policies to mitigate transboundary nature-related risks. For example, reducing biosecurity risks involves policy action on antimicrobial resistance. It is projected that AMR could cost from $300 billion to more than $1 trillion annually by 2050 worldwide (Chokshi et al, 2019, World Bank, 2017).
- **Antibiotic-dependent industry impacts.** In animals, AMR from intensive agricultural and livestock production systems leads to poor animal health which disrupts multiple critical supply chains such as food and trade of livestock. Estimates have indicated that if the persistent trends in AMR do not slow down, there will be an 11% loss in livestock production by 2050, though this may be more severe in low-middle income countries. A decline in production and trade of livestock would result in elevated prices of protein due to the decrease in protein sources such as milk, egg, and meat. In the environment, AMR as a result of contamination from pollution and waste contributes to reduction in water, soil, and crop quality, affecting food supply chains. Regulation against the use of antimicrobial growth promoters (AGPs) in the livestock industry also poses a transition risk, as it potentially lowers productivity and increases production costs. There is evidence to suggest that this effect may be more pronounced in low-income countries.

Acute Component:

- **Major livestock/poultry disease.** AMR in animals increases the risk of a major pandemic affecting livestock and poultry. In this scenario, an animal-borne pathogen (e.g. avian influenza or H1N1 swine flu) becomes widespread, meaning severe control measures are needed, and leading to widespread culling and collapse of the meat industry, and related industries, e.g. those that produce animal feed. These risks are exacerbated by several factors, including climate change, which leads to intensive indoor-rearing to reduce GHG emissions and energy costs; an increase in global meat consumption, and global deforestation for cattle ranching, which increases the potential for human-wildlife interaction and the emergence of zoonotic disease. Historically, major livestock diseases such as Foot and Mouth have been controlled, but at a substantial cost; there is also the potential for exotic diseases to gain a foothold within the UK.
- **Collapse of agricultural SMEs.** Major livestock disease resulting from AMR results in a shift in consumer preferences, leading to massively reduced sales, credit issues and the collapse of SME and agribusinesses. Precedents include Foot and Mouth disease in 2000, which cost the UK £25–30 billion through slaughter of cattle, loss of jobs and markets.
- **Global human pandemic.** In the event of AMR leading to the emergence of a major human disease pandemic, a plausible worst-case scenario is that mortality is more severe than Covid-19 (for example, double the country level mortality). This leads to widespread economic recession and a decline in GDP. Government expenditure rises as a result of aid packages similar to the furlough scheme, with a corresponding rise in borrowing. This puts the government in a poorer position to respond to future pandemics.
- **Boost to pharmaceuticals.** The emergence of a major pandemic results in significant growth for the pharmaceutical sector in line with the increased funding given to research and development of vaccines experienced during Covid-19. However, this may be mitigated by pressures to offer vaccines on a not-for-profit basis, and declining biodiversity which impedes the search for new treatment

Chapter 5. Macroeconomic Impacts of Nature-Related Physical-Risk Scenarios

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This Chapter examines the macroeconomic impacts of biodiversity loss and environmental degradation. It generates a set of quantitative scenarios based upon the narrative storylines developed in Chapter 4. The analysis uses the NiGEM model, as this model is well-used by Central Banks around the world and was adopted within the NGFS climate scenarios. It takes as an input the nVaR analyses from Chapter 3 and combines this with additional information on second-order impacts of shocks to build the quantitative scenarios. The first section below introduces the model, then we describe the quantitative scenarios and present the results. The final section discusses potential systemic risk dimensions not captured within NiGEM.

5.1. Methodology

5.1.1. Model Overview

The National Institute of Economic & Social Research (NIESR) has provided policy makers and private sector organisations around the world with a peer-reviewed global econometric model, the National Institute Global Econometric Model (NiGEM), since 1987. The model is used for economic forecasting, scenario analysis and stress testing and has been in continuous development for over 30 years to remain relevant as economic behaviours, structures and theories have evolved. NiGEM represents a closed world, where outflows from one country or region are matched by inflows into other countries and regions. NiGEM is an Econometric model, in that key behavioural equations are econometrically estimated using historical data. This ensures that the dynamics and key elasticities of the model fit the main characteristics of individual country data. From a theoretical perspective, NiGEM can be classed among global general equilibrium macroeconomic models, which are fundamentally grounded in Walrasian general equilibrium theory. It therefore strikes a balance between theoretical underpinnings that guide economies towards long-run market clearing equilibria, and data-driven individual country characteristics that fit the main characteristics of real-world data outturns. NiGEM consists of individual country models for the major economies built around the national income identity, and contain the determinants of domestic demand, trade volumes, prices, current accounts, and asset holdings. NiGEM has been used extensively by Central Banks and is the macroeconomic model used in the Phase 3 NGFS climate scenarios. Further details on model and the transmission channels used in the analysis are given in Annex 5.

5.1.2. Generating quantitative scenarios to input into NiGEM

The development of shocks using NiGEM comprises of four key components conducted collaboratively between NIESR, the University of Oxford and the University of Reading:

- **Narrative:** The shock being investigated and the reasoning behind the shock (Chapter 4)
- **Source:** Area of the economy that causes the movement away from the base case:
  - Whether the source of the shock is domestic or international.
  - Whether the shock to prices, supply, demand and/or labour.
- **Channels:** Linkages in NiGEM which best describe how the shock propagates.
  - Country specific or global shock
  - Considerations of various shock components (such as demand, supply and prices) and any unintended consequences of the shock.
- **Implementation:** Determine the size of the shock.
  - Direct implementation of shock size to relevant channel(s) of NiGEM.
  - Known impact implemented as a calibrated shock to the relevant channel(s).
  - Decisions related to the policy environment (adaptive or rational expectations, monetary and fiscal policy, etc.).

The translation of the qualitative scenarios (Chapter 4) into a set of quantitative inputs into the NiGEM, and the financial risk analysis (Chapter 6), has two components – the sector-specific impact pathways and the secondary macroeconomic impact assumptions - described below. Figure 5.1 summarises the components of the scenarios quantified and input into NiGEM. In this analysis, the shocks are internally consistent and where multiple shocks are applied to model several impacts covering a single scenario, these shocks are considered anticipated and interactive. To assess the compounding impact of each component, each shock is then run as part of a stacked run where the output of each scenario is used as the input for the next scenario. The final stacked output file represents the combination of all the shocks in the stack and the base data is equal to the starting forecast data used for the first shock. To enable the team to assess the contributions of different components, each is also run separately.

Domestic Scenario	International Scenario	Health Scenario
Water quality and scarcity impacts on agriculture and energy generation	Risks to UK supply chains re pollination, soil erosion, forestry and water	Labour force impacts of higher mortality and morbidity
Soil health decline impacts agriculture	Changes in trade and commodity prices	Increased public expenditure on public health to combat disease
Agricultural supply shock impacts prices	Reduced biofuel production puts upward pressure on oil prices	
Increases in health expenditure due to air pollution and loss of recreation	Growing global macroeconomic uncertainties lead to increase in investment and term risk premia	Fall in export shared of advanced economies due to production decline
Labour productivity impacts of pollution and biodiversity loss		

Chronic

Acute

Domestic Scenario	International Scenario	Health Scenario
Amplified impacts of water and air related to heatwave and wildfire	Impacts on UK supply chains linked to El Nino drought conditions globally	Major livestock and poultry disease outbreaks lead to fall in trade shares
Labour impacts increase due to heat and air pollution from wildfire	Multiple breadbasket failure linked to El Nino and nature leads to increase in both import and export prices	
Amplified agricultural supply shock		AMR-driven pandemic leads to economic shutdown a la Covid reducing productivity and household consumption and increasing non-commodity prices
Water constraints lead to price shock and public expenditure	New geopolitical instability manifests as increases in oil prices and reduced prices of government bonds	
Increased risk premia due to disasters	Public expenditure to counteract impacts on public and business	

Figure 5.1: Stacked components of impacts quantified for the domestic, international and health scenarios. The top section shows the chronic component and the bottom, the acute components. In blue are components derived in the sector nVaR analysis (Section 5.1.3) and in orange are components derived through analysis of secondary effects (Section 5.1.4).

5.1.3 Sector-specific impact pathways

Figure 5.1 shows the components of the quantified scenarios derived from the nVaR analyses from Chapter 3. As a simple stress test, for both the domestic and international scenario, we assume that the chronic change is equivalent to sector impacts reaching a 1-in-10-year severity level today by 2035 (i.e. a gradual linear increase in sector impact to the 0.9nVaR over twelve years). The acute shock is defined in terms of a 1-in-100-year severity level and imposed between 2030-2032 to match the qualitative storyline outlined in Chapter 4. The ecosystem service impacts included in the two scenarios – summarised in Figure 5.1 - similarly match those in the qualitative storylines, combining for example, pollination, invasive species, soil quality impacts, surface water impacts according to the scenario. Figure 5.2 shows the quantified hypothetical scenarios. The domestic scenario is much larger as this captures a direct risk to sectors, whereas the international scenario captures only risks transmitted to the UK via supply chains. In theory therefore, the two could be combined to study the compounding effect of both domestic and international nature-related risks; this is the approach taken in Chapter 6 as part of the financial stress test. Note that there is no sectoral impact pathway assumed for the health scenario, as the impacts are not specific to one sector. The sector-specific impacts are integrated into the NiGEM model in the same was as for the NGFS Phase 4 climate scenarios; that is as a direct shock to production. The model is then able to equilibrate, including through adjusting prices and demand, hence the GDP impact is lower (see later).

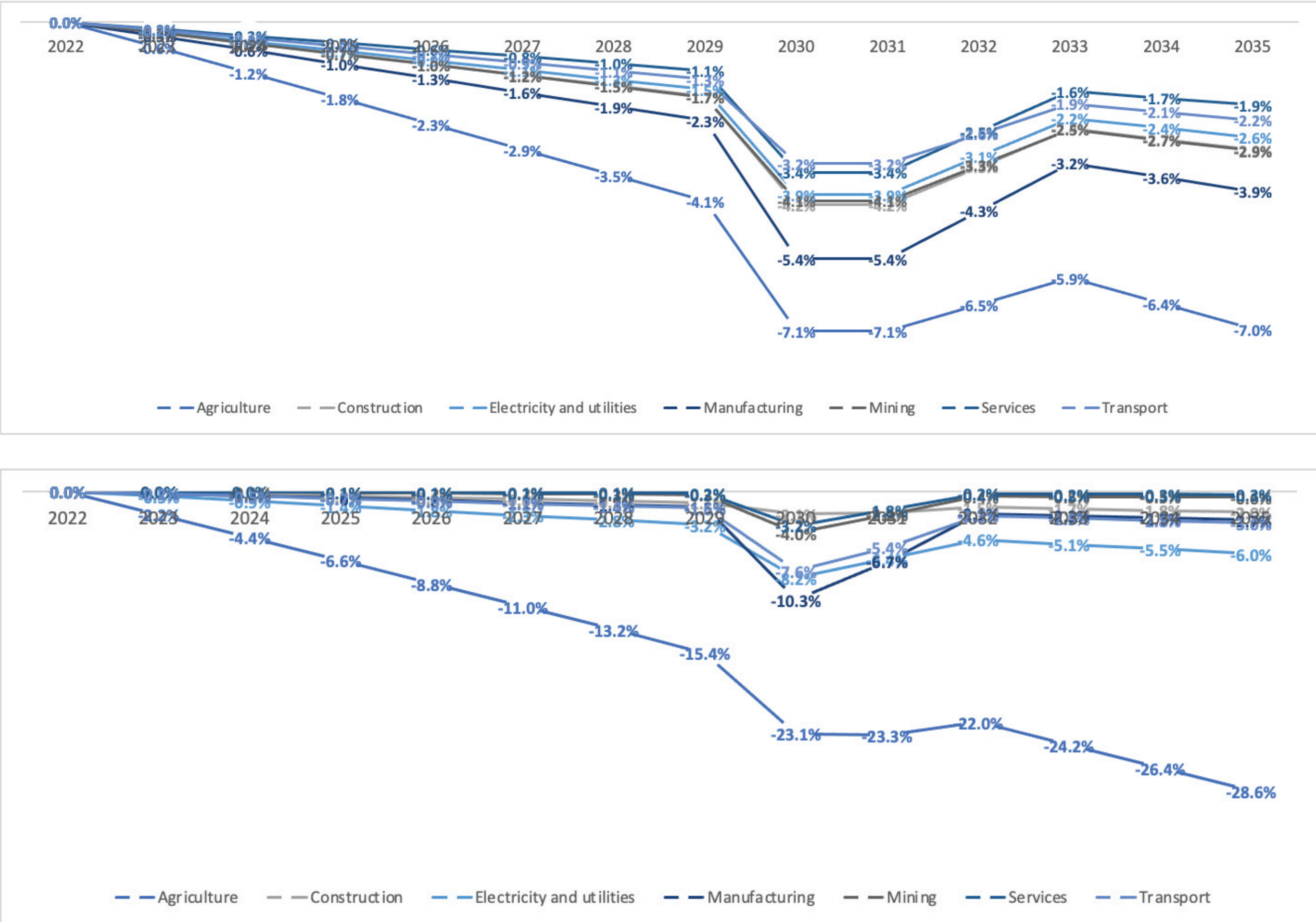


Figure 5.2: Hypothetical sectoral impact pathways over the ten year scenario window (2025-2035) for the international (bottom) and domestic (top) scenarios. The x-axis shows the percentage reduction in sector production versus the baseline (defined in 2022).

5.1.4. Capturing non-sector specific effects

Quantitative scenarios for non-sector specific effects, such as impacts on prices and labour productivity, are calibrated using assumptions based on the literature and historical analogues (see Annex 6 and Supplementary Materials 1 for details). The components of each scenario are summarised in Figure 5.1. The NiGEM model takes the resulting timeseries as inputs then simulates the macroeconomic impact on the UK (and globally) in terms of key macroeconomic variables, including GDP, inflation, and public expenditure.

5.1.5. Incorporating the impacts of climate change

The UK economy will be affected by the impacts of climate change and environmental degradation at the same time, and these will combine in non-linear ways to amplify the impacts. In the scenarios, we explicitly capture relevant interplays between climate change and nature, for example in the acute shocks of the domestic and international scenarios, the impacts are amplified by a drought and El Nino respectively. However, the scenarios do not include the baseline (chronic) increase in climate-related physical and transition risks. For this reason, we also run the scenarios with and without the additional impacts of climate change. For this, we use the NGFS climate scenarios. We select two scenarios consistent with the "too little, too late" world utilised in this study: the NGFS NDC and Current Policies Scenarios. Both of these scenarios exceed 1.5C and the Current Policies scenario reaches around 3C by the end of the century. Both reach around 2C by 2050. Physical risks are accordingly high and near-term transition risks low. The main NGFS GDP-based physical risks data are complemented by data from the NGFS-Climate Analytics Climate Impact Explorer on average annual losses for heatwaves, drought and flood to attempt to capture some of those risks known to be missing from the NGFS scenarios.

5.2. Results: Macroeconomic Impacts of Nature-Loss

Biodiversity loss and environmental degradation create demonstrably material risks for the UK economy and financial sector. Figures 5.3-5 give the impacts on GDP of the three scenarios relative to baseline GDP growth. Results are given for nature impacts alone (in blue) and combined with the impacts of climate change under a higher (grey) and lower climate scenario (in orange)[20]. The three groups of bars show the GDP impacts in the late 2020s due to chronic risks alone (left) and the maximum size of the acute shock (which occurs around 2030-2031).

Under our three scenarios, the compounding of nature and climate-related damages in the coming decade could lead to declines in UK Gross Domestic Product (GDP) of over 8%, or up to just over 14% in an extreme scenario where a major ecologically-driven health-related ecological shock (AMR-pandemic) is combined with climate change.

Nature-related risks are as detrimental or more so than climate-related risks. Looking only at the 'pure' nature-related shock (no climate change) for a domestic or international nature-risk scenario, losses of around 6% GDP are possible in the coming decade. Without climate change, all three scenarios have a chronic impact of 1% - 3% GDP loss relative to the baseline by the late 2020s, with the greatest impacts in the domestic and international scenarios. This is amplified to around 6% in the acute shock for the domestic and international scenarios.

Environmental degradation increases the chance and impacts of an acute climate or health shock, and the combined effect would have a very material impact on the economy. For example, our scenario analysis points to a 12% GDP impact for a major health shock related to growing anti-microbial resistance caused by changes in land-use and deforestation globally.

[20] Phase 3 scenarios: https://www.ngfs.net/ngfs-scenarios-portal/

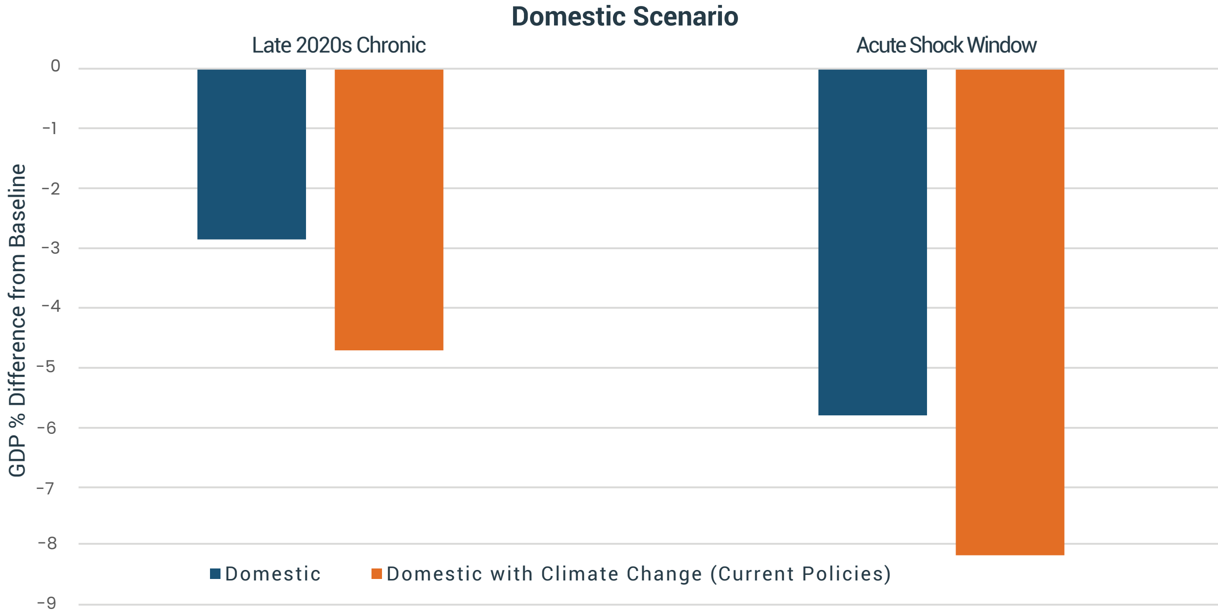


Figure 5.3: GDP Impacts for the domestic scenario

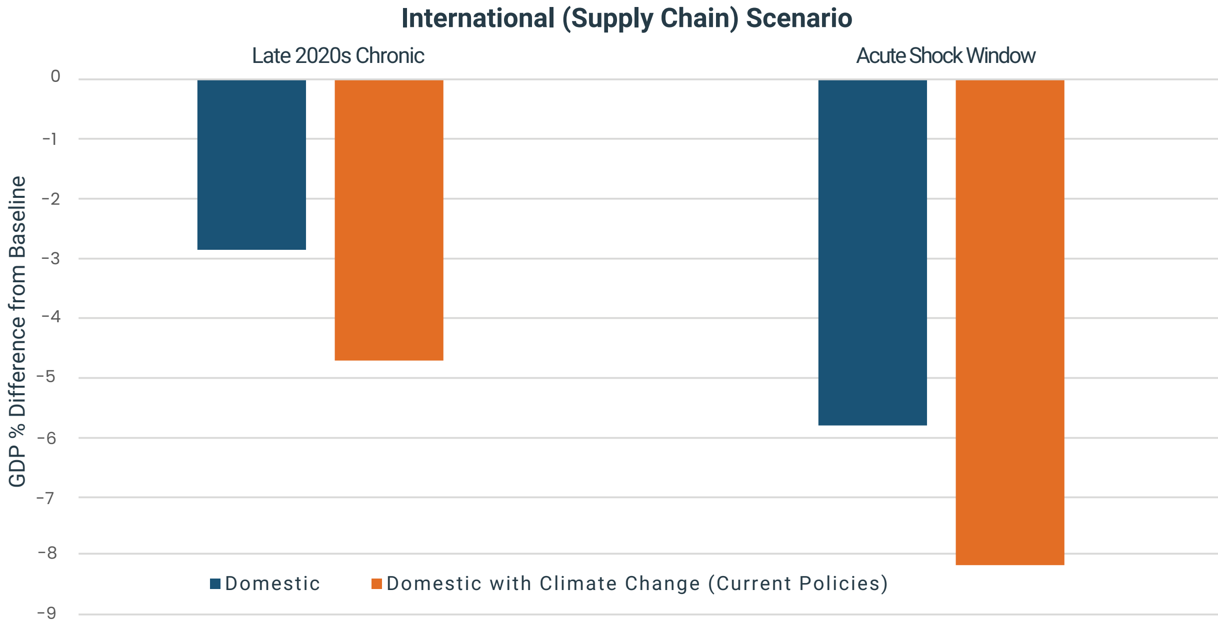


Figure 5.4: GDP Impacts for the international (supply chain) scenario

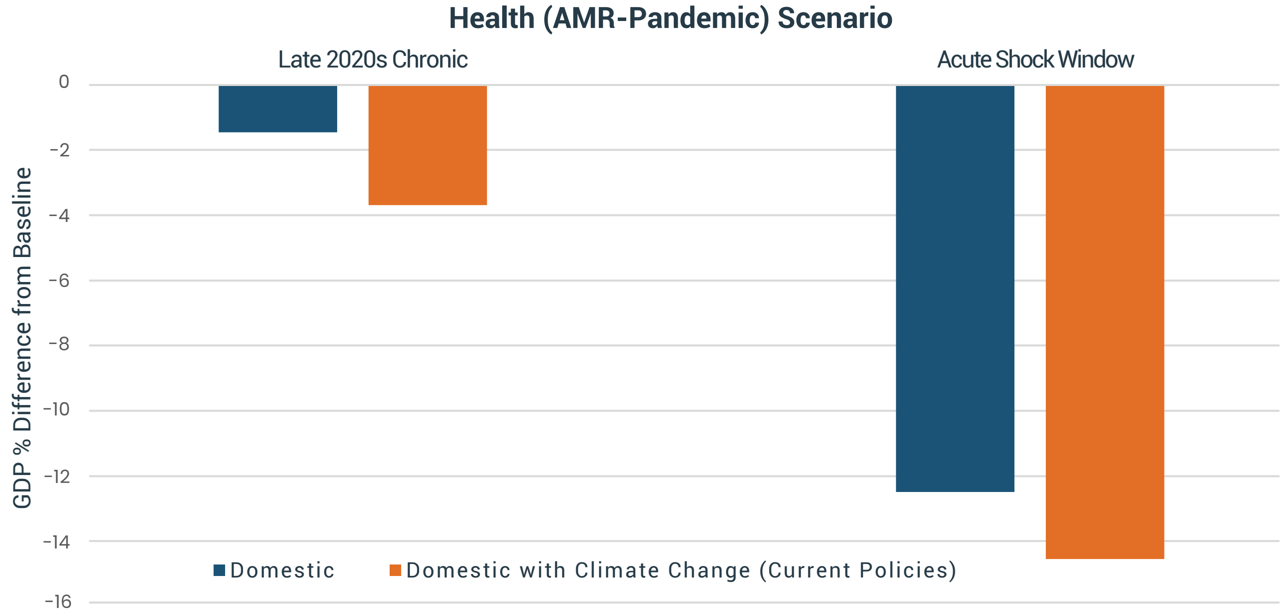


Figure 5.5: GDP Impacts for the health (AMR-pandemic) scenario

Recovery following the acute shocks is modelled to occur relatively rapidly, e.g. within two years, but the chronic changes maintain persistent and increasing reductions in GDP. The timeseries are shown in Figure 5.6. The relatively rapid recovery from the acute shocks is an outcome of the way the scenarios are defined but is consistent with historical shocks such as COVID-19 and the Global Financial Crisis. The international scenario is more persistent as this assumes prices, trade restrictions and the fiscal implications for EMDEs take time to recover after the shock. Arguably, given lessons from the Global Food Price shock in 2008-2010 the risk of ecological regime changes and growing conflict in parts of the world linked with ecological stresses, a nature-driven shock could be far more persistent. Indeed, a larger ecological shock associated with major regime change, such as the loss of the Amazon rainforests, would have permanent and severe impacts. As such, these scenarios should be seen as conservative and further work is needed in this area.

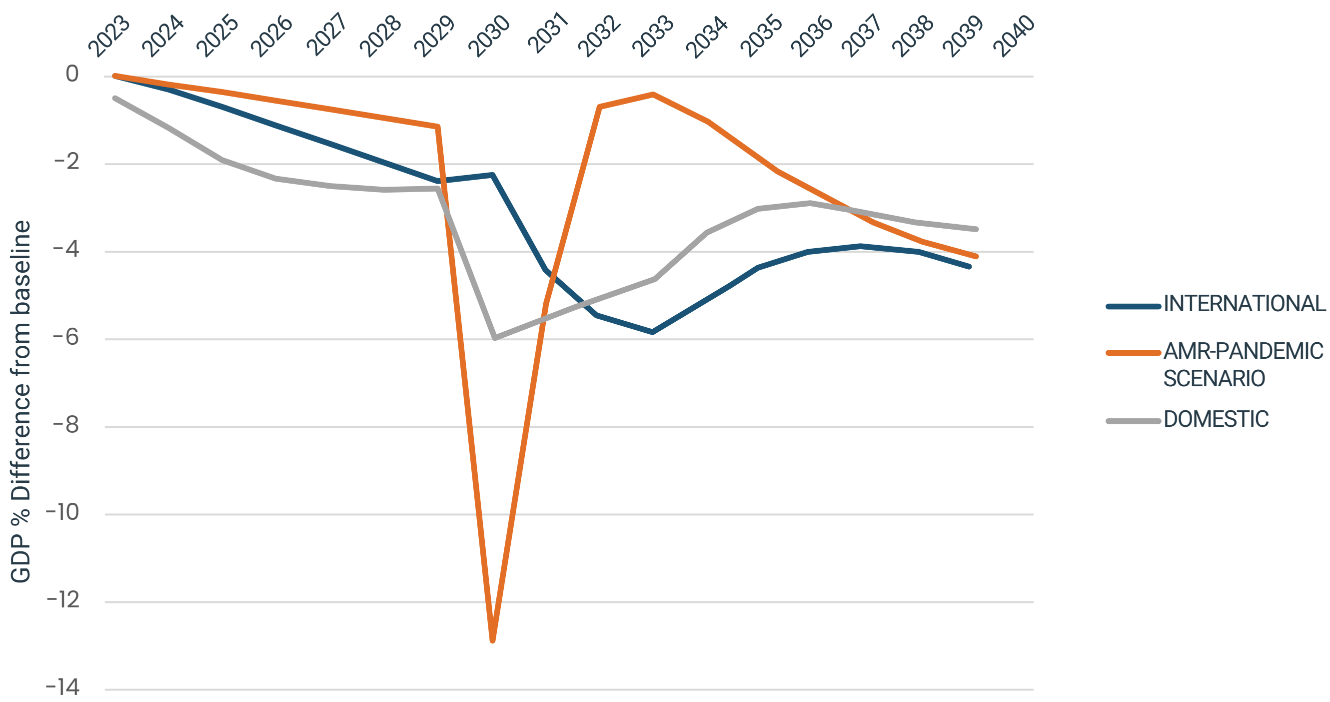


Figure 5.6: timeseries of GDP impact of the three scenarios (no climate change)

More gradual, chronic changes in ecosystem health alone globally create material impacts for the UK. Our scenarios include a severe but plausible acute shock, yet we find that even without this the impacts of chronic changes in ecosystem services are material. Figure 5.7 shows the contributions of the sector nVaR and the chronic and acute secondary effects separately to explore what is driving the overall results. It is clear for the international scenario that the chronic secondary effects are the largest contributor to the impacts. For the domestic scenario, the sector-specific and secondary effects are roughly equal size. This implies that it is essential to manage risks associated with chronic effects, as well as prepare for acute shocks. Further, it implies that in risk management, it is important to consider the secondary macroeconomic effects, as well as the primary sector-specific damages. Just considering sector-specific effects, would lead to underestimation and under-preparedness.

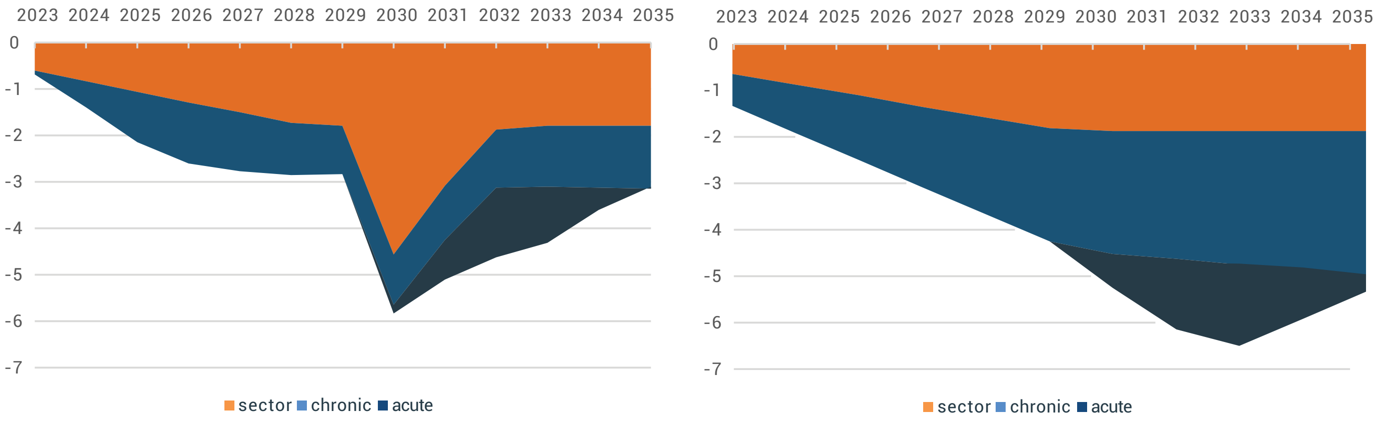
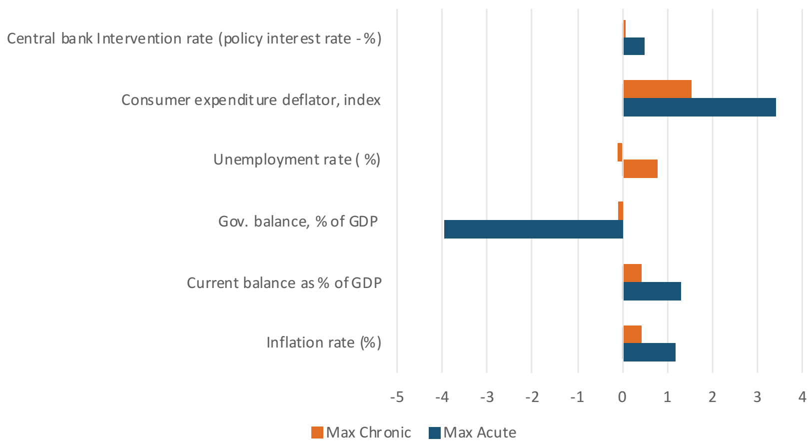


Figure 5.7: GDP impacts for the domestic (left) and international (supply chain; right) scenario with the individual contributions of the sector-specific nVaR and the chronic and acute secondary-effects shown.

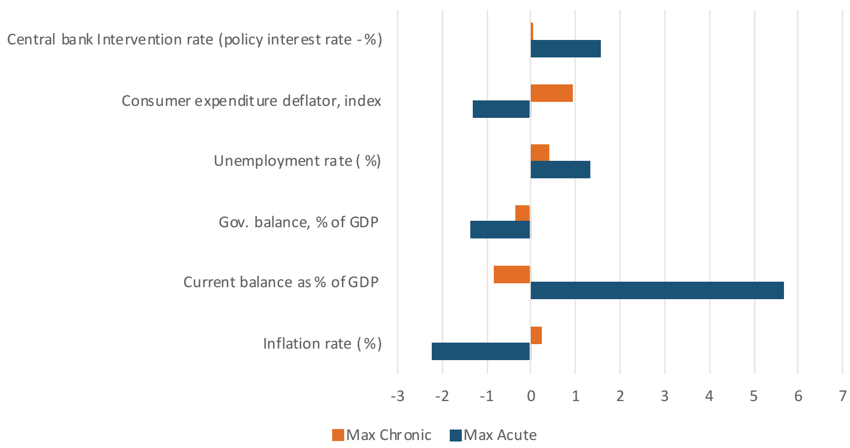
The scenarios also demonstrate that nature-related risks can have impacts on metrics of wider macroeconomic performance, including interest rates, unemployment, prices, public-sector finances, inflation and the current account balance. The chronic impacts show minor to moderate shifts by the late 2020s and this varies by scenario (Figure 5.8). However, the acute shocks can drive more significant shifts. For example, both the domestic and international scenarios lead to increases in inflation, associated with increases in commodity prices. All scenarios entail a significant deterioration in government's deficit as a %GDP as public expenditure rises to cope with the shock.

Domestic Scenario



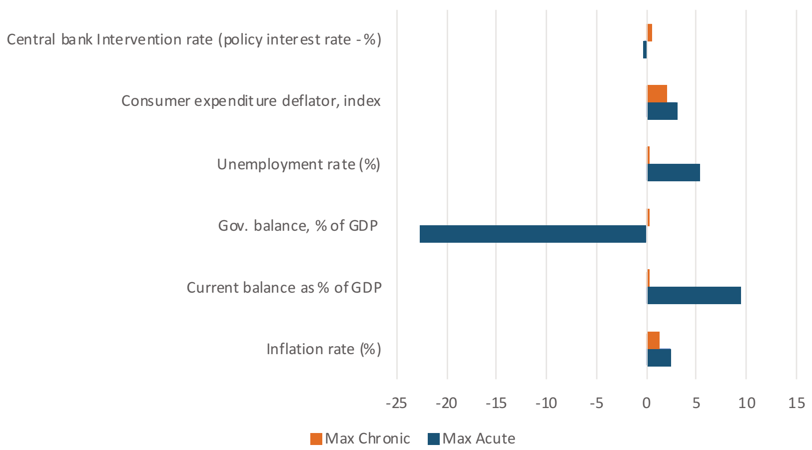
- Prices increase due to pressures on food and energy and inflation rises accordingly. The monetary policy response leads to higher interest rates.
- Increases in public spending on health leads to higher government deficit
- Current account balance increases as demand with rising prices (import less from overseas vs exports)
- Unemployment above baseline due to slower growth of the economy

International Scenario



- Prices continue to rise throughout entire period, while interest rates fall due to the fall of nominal GDP (money stock proxy) outweighing the inflationary impact associated with the shock.
- Prices fall from this acute shock as it is a shock to business confidence which in turn depresses both the demand and supply side of the economy and monetary policy tries to offset this decline (by cutting interest rates). Unemployment increases, as does public expenditure, and current account balance rises as demand falls and the UK imports less.

Health Scenario



- Significant increases in public expenditure to deal with the health emergency
- Unemployment increases due to lock-downs in the acute shock
- Consumer prices increase as supply chains are interrupted and inflation accordingly rises
- Current account balance as increased as demand in the economy falls and so imports fall relative to exports

Figure 5.8: Timeseries of macroeconomic variables and brief descriptions

5.3. Systemic Risk Dimensions

Not all the impacts of the three scenarios can be robustly quantified and modelled within NiGEM. In line with the NGFS guidance, we term these 'systemic risk dimensions' (NGFS, 2023a). This study has gone further than previous studies in incorporating compounding, cascading impacts of nature and climate change. However, it is not possible to anticipate all risks and there are many of these transmission channels that are harder to parametrise as they contain indirect pathways whereby social, cultural or political processes are involved, making quantitative impacts harder to assess. Nevertheless, in many cases we know these pathways can likely be materially important, as economic or financial impacts have occurred in other countries or past times. For example, it is clear that civil unrest prompted by food insecurity and other factors like climate change can have major disruptions for economies and their financial systems (e.g. the Arab spring; Johnstone and Mazo, 2011). Such transmission channels can only be partially captured in the NiGEM modelling. Figure 5.9 illustrates the systemic risk dimensions for the domestic scenario. Annex 7 gives examples of some of the key potential systemic risk dimensions, and this will be an area of future work.

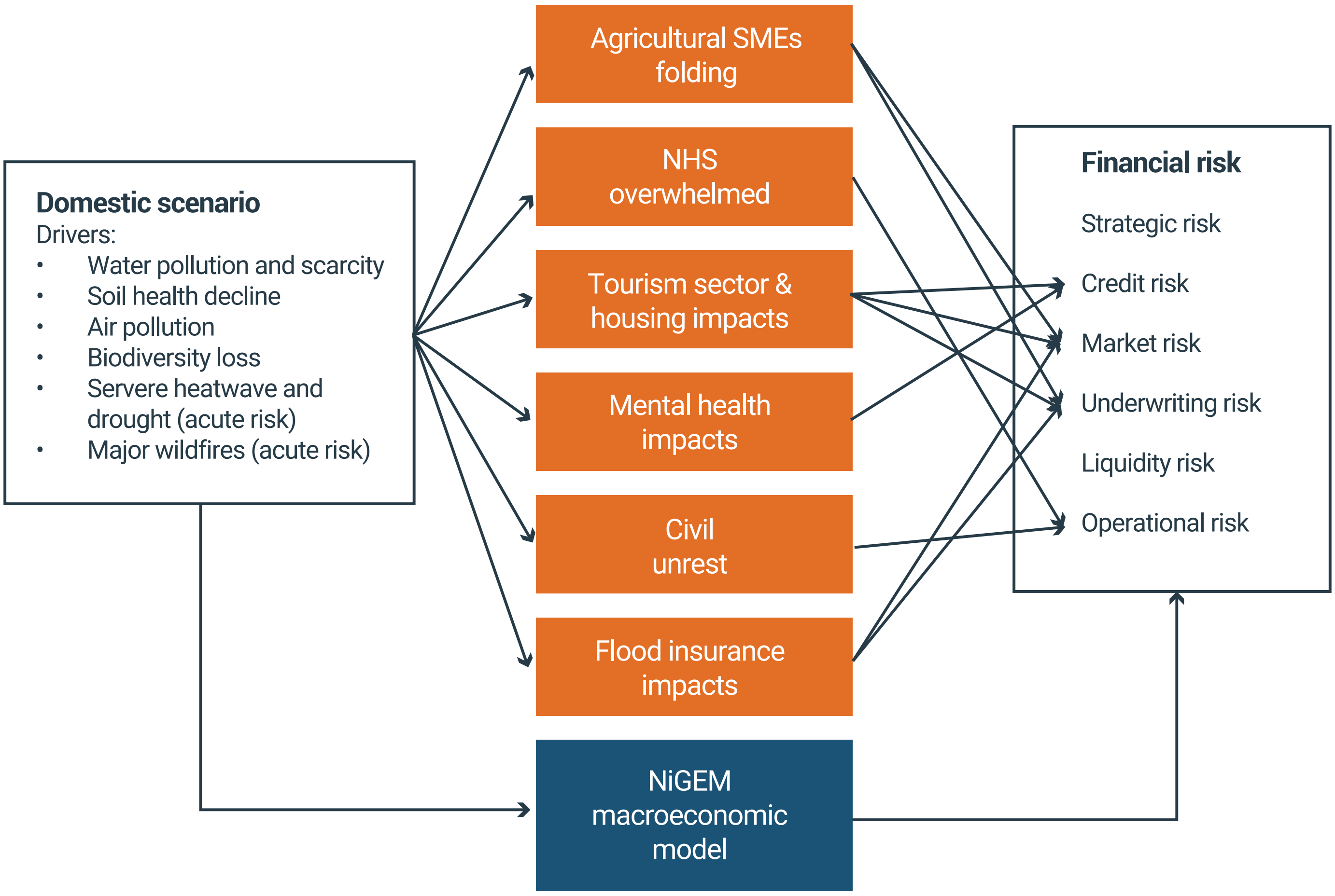


Figure 5.9: Example of systemic risk dimensions—indirect risk transmission pathways— which are not currently captured in the macroeconomic modelling in this report. Further details available in Annex 7 and the Supplementary Materials.

Chapter 6. Preliminary Financial Stress Test

Authors: Stefano Battiston, Irene Monasterolo, Nicola Ranger

In this final section, we provide a preliminary 'nature stress test' by assessing the financial impacts of the nature and biodiversity loss scenarios (Chapter 4 and 5) on the domestic loan portfolios of seven UK banks. In order to assess nature and biodiversity credit risk, we assess the difference in financial valuation of the portfolio of assets for a specific scenario compared to a baseline scenario. We interpret the relative difference between the scenario and the baseline as the adjustment in financial valuation of loans conditioned to the change in investors' expectations about the materialization of the different nature-related risk scenarios (e.g. due to new information). Hence, there are several differences to the NVaR analysis conducted in Chapter 4: firstly, the analysis accounts for not just direct impacts but also the response of investors to those impacts; secondly, it assesses the impact of the losses related to nature impacts on the whole portfolio of the banks and so gives a sense of the 'stress' on the bank portfolio overall, which is a metric that is relevant for considering financial stability.

From a methodological point of view, we build upon a stream of work in climate scenarios-contingent financial valuation and climate stress-test, that is now established in the context of climate-related financial risks (see e.g. Battiston et al. 2017, Battiston et al. 2023, Battiston and Monasterolo 2020, Monasterolo et al. 2018), and has been widely applied for climate financial risk assessment by central banks and financial regulators (e.g. Battiston et al. 2019, 2020, Roncoroni et al. 2021 (Banco de Mexico), FINMA 2021, MAS 2023).

It is important to note that this analysis introduces and illustrates the methodology for nature and biodiversity scenario-adjusted financial valuation and stress test. Its results, however, should be considered as preliminary being limited by the granularity of data available. Future developments would aim to conduct such analyses in close cooperation with financial institutions in order to incorporate counter-party level data to increase the granularity of the information available, and assess the second-order risks (so far the analysis takes as an input only the sector impact data).

A challenge of this analysis is that a large part of the portfolios of UK banks relates to finance – i.e. financial transactions with other financial institutions. It is exceptionally difficult to assess the nature-related risks to such assets given the lack of transparency over which aspects of the real economy these financial assets are linked to. For this study therefore, like other studies, we conduct this analysis with and without these assets, to avoid underestimating the risks.

6.1. Methodology

We aim to derive a relation between the economic impacts of biodiversity loss and environmental degradation and the financial risk of the banks, for simple debt instruments such as loans or zero-coupon bonds. To this end, we build on a stream of works (see e.g. Battiston and Monasterolo 2020, Battiston et al. 2017, Monasterolo et al. 2018, Roncoroni et al. 2021, Battiston et al. 2022) which albeit focusing on climate risk, have established the approach of scenario-contingent valuation into sustainable finance.

There are of course many differences between climate-related economic impacts and nature-related economic impacts. Yet there are also similarities in the use of scenarios that we can leverage on. We build on the scenario-contingent valuation in Battiston et al. 2022's credit risk model (CLIMACRED), and we tailor and apply it to nature and biodiversity loss scenarios described in Chapter 4 and 5.

We consider a set of scenarios that includes a "Baseline scenario" (abbreviated as B), in which biodiversity loss impacts do not occur, and scenarios of nature and biodiversity loss i.e., a "Domestic Scenario" (D) and International Scenario ("I"):

- The baseline scenario does not consider biodiversity loss and environmental degradation. This scenario corresponds to a situation in which investors neglect biodiversity risk. Indeed, the relation between biodiversity risk and finance has been little documented and analysed so far. Thus, the rationale to assume that investors have not formed expectations about biodiversity risk (because complex, not happened so far).
- In the domestic scenario, there is a growing chronic impact and an acute shock on a selection of ecosystem services in the UK, which impact directly on the UK economic activities (indirect impacts from international trade via the portfolio are not considered).
- In the international scenario, only the indirect effects on UK activities is considered, resulting from shocks on chronic and acute shocks on ecosystem services outside the UK, through supply chains.

In this Chapter, we analyse the domestic scenario and, as a stress test, we assess risk for a combined scenario, including both the domestic and international scenarios given that they both explore independent aspects of risk (noting that the international scenario here captures only the risk to the domestic portfolio). The full methodology is given in Annex 8.

We consider the portfolio of loans and advances of the seven largest UK banks, i.e. Barclays, HSBC, Lloyds, Standard Chartered, NatWest, Santander UK, and Nationwide. We examine only the domestic holdings of banks for this preliminary assessment (note therefore that results are nil for Standard Chartered as its holding are overseas). The total value of the analysed portfolios is close to 717 GBP billion, so a subset of the full UK financial system. The largest allocation of loans of the seven banks is to financial activities, followed by manufacturing. We exclude the financial holdings from this analysis, given that we have no information about the real economy sectors that these assets are financing and therefore, no way to assess the nature-related financial risks associated with them. In this study, we effectively assume that those assets face a risk that mirrors that of the rest of the portfolio. Further work is required with financial institutions to clarify this assumption and refine the analysis.

6.2. Preliminary Results

Across the sectors, we find potential adjustments in average loan values of up to -9.5% for the agriculture sector in the domestic scenario, -2.3% for electricity and utilities and around -1% for manufacturing and transport (Figure 6.1). The adjustments are assumed to occur in 2028 based upon projected revenues over the following five years.

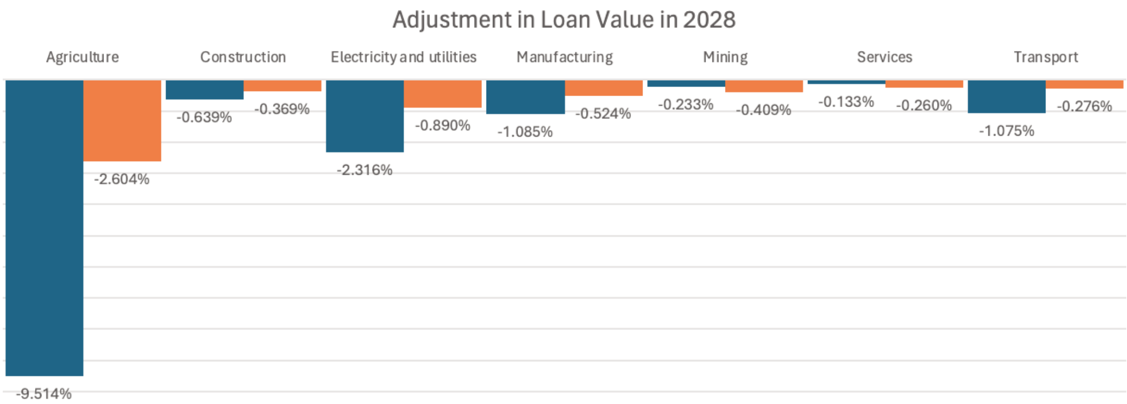


Figure 6.1: Adjustment in loan values per sector under the domestic (blue) and international scenario (orange) for UK domestic holdings.

Looking across the portfolios of the seven largest UK banks, the analysis indicates possible adjustments in the values of all domestic holdings of up to 4.0– 5.2% for the two scenarios for particular sectors and banks. The results are strongly heterogenous across banks, depending on the structures of their portfolios. Depending on the bank, the most at-risk sectors may include agriculture, utilities, real-estate or manufacturing. In Table 6.1, we report the adjustments in the values of the holdings in each sector relatively to the portfolio of domestic holdings outside finance and services. The interpretation of each cell is that, conditional on changing expectations of the market about the realisation of the future nature-related risk, a loss of % would occur relatively to the subset of holdings in securities of domestic companies in economic sector outside finance and services. If the portfolio was considered including finance and services the numbers would be lower (see Annex 8 for results), however we caution how such results are interpreted given the lack of transparency on their nature-related risks.

	Bank 1	Bank 2	Bank 3	Bank 4	Bank 5	Bank 6
Domestic Scenario	1.29%	1.48%	3.95%	0.64%	2.26%	1.45%
Domestic + International Scenario	1.85%	2.08%	5.16%	1.01%	3.04%	2.04%

Table 6.1: Adjustments in the values of holdings of each bank in a given sector relative to its portfolio of domestic holdings in the sectors excluding finance and services, conditional to change in expectation from the Baseline Scenario to the Domestic Scenario of biodiversity risk.

These preliminary results suggest that even in the short term nature-related risk is non-negligible, especially if the losses are considered in relative terms to specific fractions of the portfolio. It is important to note – as discussed in Chapters 4 and 5 - that these scenarios should be considered as very conservative, in that while they go further than other studies in capturing complex, cascading and compounding risks, inevitably they do not capture all possible outcomes, including potential risks of catastrophic ecological regime change. Future analyses and supervisory authorities should consider extending the design of the analysis to include mid to long term scenarios and impacts in the economy of biodiversity loss, in order to have a more comprehensive assessment of their impact on financial stability.

The estimates are underestimates for the following reasons:

- They do not incorporate the secondary macroeconomic effects discussed in Chapter 5, only the sector-specific effects, which the modelling shows is only around one third of the total impacts on the macroeconomy.
- Only consider the domestic holdings of banks, and not the significant international exposures, particularly for banks 2 and 7 (Chapter 3). This is important because two of the banks (HSBC and Standard Chartered) have largely overseas portfolios and those risks are not included in this analysis. This is a topic for future research.
- Results are considered over a near-term time horizon so miss longer term effects.
- Do not consider more extreme or persistent scenarios that are expected to be associated with nature-related risks, particularly beyond the 2030s
- No accounting for transition risks

Chapter 7. Summary & Recommendations

7.1. Conclusions

Biodiversity loss and environmental degradation create demonstrably material risks for the UK economy and financial sector, in addition to their wider social impacts. These impacts are near and present; reflecting the significant decline in the functioning of critical ecosystem services in the UK and around the world. While the analysis presented in this report is preliminary, these conclusions are clear and supported by multiple lines of evidence. Our headline findings include:

1. **The deterioration of the natural environment in the UK and around the world could slow economic growth and lead to major shocks that could result in GDP being 6% lower than it would have been otherwise by the 2030s under two scenarios and 12% lower under an AMR-pandemic scenario.** This is equivalent to wiping around £150-300 billion off GDP. These are greater than the impact on GDP experienced in the Global Financial Crisis, in which UK GDP fell by around 4% to 6%, and - for the AMR-pandemic scenario - greater than the GDP impact of the COVID-19 pandemic when GDP fell 11% over 2020.
2. **Gradual (chronic) year-to year environmental degradation is as detrimental or more so than climate change.** Chronic changes in ecosystem health alone, for example due to local air and water pollution and global deforestation, create material impacts. The 'pure' nature-related impacts (no climate change) on growth are equivalent to around a 3% GDP reduction versus baseline growth in the coming decade and much more in an acute shock scenario and over the longer term. This means that nature-related risks are doubling the scale of physical climate related risks based on NGFS scenarios.
3. **Environmental degradation increases the chance and impacts of an acute climate or health shock, and the combined effect would have a very material impact on the economy.** For example, soil degradation, invasive species and pests amplify the climate impacts on agriculture, and impacts of climate on ecosystems amplify the health risks.
4. **For two of the scenarios, the chronic year-to-year environmental degradation is as damaging as the more sudden acute shocks.** Gradual environmental degradation constitutes around half of the size of the acute shocks by the early 2030s - for example, with domestic scenario chronic impacts of 3% GDP compared with 6% for the acute shock - and continues to worsen over time without action.
5. **In reality, the impacts of biodiversity loss and environmental degradation will not be felt alone but will compound with climate risks.** Both are happening at once and there are strong feedback effects between the loss of natural capital and climate change. We find that the compounding of nature- and climate-related damages could result in UK GDP that is more than 8% lower than it would otherwise be by the 2030s, or 14% in an extreme scenario of an ecologically-driven health crisis combined with climate change.
6. **Around half of UK nature-related risk comes from overseas, through supply chains and financial exposures.** Our analysis shows that the £3.8 trillion of UK financial assets assessed depend upon many trillions more globally, of which the majority have a high or very high dependence on nature. Exposures to overseas risks are most material (in financial terms) for the services and manufacturing sectors. The highest risks across sectors are derived from nature's provision of water and nature's ability to regulate climate, moderating the risks of floods, storms and drought.
7. **Looking across the portfolios of the seven largest UK banks, the analysis indicates possible near-term adjustments in the values of domestic holdings of up to 4-5% for particular sectors and banks from nature-related risks alone** (no climate change). The study conducts the first (independent) aggregate financial 'stress test' of banks for nature based on publicly available data. Different banks show very different risks in terms of their scale and characteristics depending on the structures of their portfolios. Depending on the bank, the most at-risk sectors include agriculture, utilities, real-estate and manufacturing. The 4 – 5% is conservative. These risks will compound with climate change and increase over time. The broad and correlated nature of these risks indicate that in the longer-term, nature-related risks could may be a threat to financial resilience.

8. **The agricultural sector is most at risk in percentage terms, but the largest risks in economic terms are to the services and manufacturing sectors.** Manufacturing risks come largely via supply chains and predominately related to loss of regulation of water quantity and quality disrupting production processes. Construction is also highly exposed due to land use change and raw material consumption and this is a particularly important driver of risk to financial institutions with high real-estate exposures.

7.2. Implications & Recommendations

The findings of this study take us further than previous studies to-date by clearly demonstrating the materiality of nature-related financial risks to the economy and the financial sector, and the potential for financially material compounding impacts between climate and nature. These are preliminary estimates but all the evidence points to them being conservative. In addition, our analysis is focused on the near- to medium-term, and the evidence clearly shows that without action, these risks will increase over time with the potential to cross ecological tipping points that could accelerate and amplify the severity and persistence of impacts markedly. While our focus has been on the UK, the findings and underpinning methodologies are relevant to all countries.

Further work is required to fully assess the implications of these findings for regulation. This study did not explore this explicitly. However, based on the evidence provided here and in other studies, we believe that there is a case for action by Central Banks and supervisors, regulators and governments to assess if and how nature-related risks need to be incorporated within existing prudential and other financial and fiscal regulatory and policy frameworks, and for financial institutions to take steps to assess the potential materiality for their own portfolios.

It is clear, however, that the potential risks to financial stability can be sizeably reduced with an early and orderly transition toward a nature-positive resilient net zero economy, both in the UK and globally. Given the high exposures to transition risks, early action by firms to begin to price in and manage nature-related risks and impacts will deliver benefits. This can also begin to steer financial flows away from activities that damage nature and toward nature-positive activities, thus reducing the physical nature-related risks to society and the financial sector.

Further, our findings highlight several unique characteristics of nature-related risks that may present new challenges for financial stability which may necessitate explicit measures within supervisory, regulatory and policy frameworks:

- **Scale and transmission.** The risks that we identify go beyond climate change and operate through different drivers and risk transmission channels that are not captured as part of current approaches to climate risk analysis. In some cases, nature-related risks amplify climate risks, for example, the impacts of land-use change on climate regulation and over extraction on water scarcity; and so arguably a more comprehensive approach to physical climate risks (beyond practice today) could integrate these. However, the sizable risks related to pollution, soil erosion, pests and diseases, and pollination are not part of climate risk assessments. Similarly, the potential risks via health threats such as AMR go beyond what we saw with COVID-19. AMR in particular could amplify the impacts and make recovery times longer.
- **Sequential and compounding threats.** Environmental degradation erodes the natural capital on which economies are based, reducing the resilience to other threats such as climate shocks and disease outbreaks, as well as increasing costs of doing business and reducing productivity, thus increasing economic vulnerabilities. Our economy and financial system could be hit not just more severely as a result of environmental degradation but have less time and capacity to recover between shocks.

- **Tragedy of the horizons.** Analogous to the words of Mark Carney in 2015 - once nature and biodiversity loss become a defining issue for financial stability, it may already be too late. The complex nature of these risks makes them difficult to anticipate, abrupt and non-linear. There are potential local or global ecological tipping points, which once crossed could lead to rapid, irreversible regime changes that could seriously impact key supply chains over large areas and have persistent and cascading implications for global trade, geopolitical stability and the global macroeconomic environment. Such regime shifts would precipitate rapid revaluations of portfolios and reduced confidence. We have already crossed several planetary boundaries. While Carney's 'Tragedy of the Horizons' speech assumed a 'horizon' some way beyond the business cycle, the analysis here as well as the vast body of existing ecological literature demonstrate that chronic nature related risks are already impacting our economies and risks are near and present. As with climate change, early orderly action on nature-risks will reduce the physical and transition risks and increase the opportunities with a nature-positive transition.
- **Tragedy of scale:** there is potential for severe and unprecedented events that are highly correlated across financial institutions, countries and sectors making it difficult for individual financial institutions to anticipate, price and manage the risks. These are global, interconnected, cross-sectoral risks and so the potential for cascading and compounding shocks that lead to correlated impacts across institutional portfolios is high. These could have large-scale and difficult to predict impacts. Assessing and managing such risks at the level of individual financial institutions is challenging.
- **Accumulation of risk in the system:** The fact that nature related risks are not currently included within the everyday pricing, lending and investment decisions means that potential systemic risks are accumulating. NGFS (2022) recognised that this accumulation of risk brings nature into the mandate of Central Banks and supervisors.
- **Significant information asymmetries.** The exposure of different real economy firms is opaque – far more so than even with climate risks back in 2015 when TCFD was launched - making it difficult for financial institutions and corporations to assess and manage the risks – "the more we invest with foresight, the less we will regret in hindsight" (Carney, 2015). The lack of information can lead to an unrecognised accumulation of risk across the financial sector. Enhancing the information available is essential.

The findings also have implications for climate change risk assessment. There is a strong argument for including these nature-related macroeconomic impacts within climate risk assessments, given the strong feedbacks and interconnections between climate and nature. This would double the estimated impact of climate change on the UK economy, beyond what is currently predicted by the NGFS. Ignoring these impacts contributes to the significant underestimation of climate change physical risks.

7.1.1. Actions for Central Banks, Supervisors, Regulators and Government

Given the evidence and the unique characteristics of nature-related risks, there is an urgent need to assess if and where these nature-related risks may 'fall through the cracks' of current supervisory, regulatory and policy frameworks and where this would necessitate actions. Based on such an assessment, actions may include:

- **Advancing disclosures of nature-related risks and impacts in the UK.** The high exposure of UK firms to nature-related risks shown in the analysis coupled with other studies that demonstrate the information asymmetries that are holding back risk management (e.g. GARP 2024, TNFD 2023) suggests that corporate regulations to increase disclosures at the firm level would lead to meaningful improvements in financial resilience. Taking forward the recommendations of the TNFD therefore, as outlined in the UK's Green Finance Strategy, could be an important step therefore in terms of building financial resilience to nature-related risks.
- **Broadening supervisory statements on climate to explicitly include environmental risks, and incorporating aspects of environmental degradation into exploratory scenario exercises.** The benchmark scenarios developed here could create a foundation to build one or more exploratory scenarios for firms.

There are also several low-regrets measures that can also be win-wins with climate risk management. For example:

- **An immediate priority is to encourage financial firms to begin to build capability in assessing and managing nature-related financial risks.** Existing fora such as the Climate Financial Risk Forum can support capability building across the financial sector and enable the development of best practice.
- **Advancing disclosures of asset-level information and supply chains.** Nature-related risk assessment suffers from data gaps common to climate risk management. For example, enhanced disclosures of the asset locations and supply chains would enable significant improvements in both nature and climate risk assessment and management. Regulators should also assess if steps should be taken to enhance transparency around the largest financial sector exposures of banks, where it is currently impossible to assess nature- (or climate) related risks.
- **Take timely opportunities to incorporate nature, as appropriate, fully within emerging regulatory frameworks and standards, for example the ISSB, new green taxonomies and transition plans.** This will reduce the burden on firms.
- **There is a clear and urgent case for investment in enhancing the underpinning data, analytics and modelling of nature-climate-economy interactions as a global public good.** One of the most significant constraints in this exercise, has been the availability of granular data on the state of ecosystem services in the UK and modelling of future risks. Data availability and accessibility is substantially poorer than for climate, for example. While large amount of data exist these are not necessarily those needed for economic and financial risk assessment. Further work is needed by government with the scientific community to identify the priority gaps and put in place a funded-roadmap to fill them. Box 7.1. illustrates how the NRRI could be used to help prioritise a roadmap. Given the materiality of nature-related risks for the UK economy and financial sector, there is a strong strategic case for government, philanthropies and financial institutions to invest in advancing climate-nature-economy modelling, analytics and scenarios as a public good. The NGFS (2023) similarly identified the priority need to advance modelling. An action for government could be to work with the new UKRI Integrating Finance and Biodiversity programme (IFB) as a platform for collaboration, drawing upon its substantial multidisciplinary nature expertise and links to seventeen universities across the UK.

The exposure of the UK economy to global nature-related risks provides a clear rationale to collaborate internationally to ensure material nature-related risks are addressed. Given the global nature of risks, the Financial Stability Board, the NGFS and IMF could play a key role, alongside other bodies (including the IFRS, ISSB and the G20). This is a particularly important priority for the UK given the result that more than half of the risk faced by the UK economy originates overseas and is transmitted through global supply chains.

For government, the findings highlight the material importance of protecting and restoring nature both domestically and globally, including through meeting the goals of the Kunming-Montreal Global Biodiversity Framework (GBF). The UK is already a signatory to the GBF, yet the materiality of nature-related risks to the UK demonstrated in this study adds additional urgency to put in place the mechanisms, domestically and globally, to meet these goals and targets. This includes making progress on Target 14 to align financial flows with the GBF, as well as strengthening disclosures and risk assessment. For supervisors and regulators, this means engaging internationally to ensure that sustainable finance frameworks incorporate nature risks and impacts. There is also a clear role for Government in working to align public financial flows and working with partners across the international financial architecture to upscale nature finance and fully integrate nature.

While our analysis is focused on financial risks, there are potential fiscal and wider implications for the UK that require further consideration. For government, there is a rationale for similarly exploring where nature risks may be falling through gaps within current fiscal policy and risk management frameworks and acting accordingly. Also, considering if and how to more fully integrate nature-related risks within the UK National Risk Register and the UK Climate Change Risk Assessment, building upon the NRRI.

7.1.2. Recommendations for financial institutions

For financial institutions, there is a clear rationale for taking steps to assess and manage nature-related financial risks, in line with the TNFD framework and guidance. These preliminary results suggest that even in the short term nature-related risk is non-negligible, especially if the losses are considered in relative terms to specific fractions of the portfolio. An outcome of this analysis is that banks – and wider financial institutions - should start to consider the materiality of nature-related risks in their portfolios.

Integrating nature within transition plans. Many financial institutions (and corporates) are already developing transition plans in line with emerging frameworks. Guidance by the Transition Plan Taskforce, for example, has already taken steps to integrate nature. For financial institutions and corporates developing transition plans, integrating nature within these plans from the start could be an efficient approach to addressing the risks and opportunities with the transition to a nature-positive, resilient and net zero economy.

Given that early action will minimise transition risks and maximise opportunities, there is a rationale to begin working with clients to support their transition. Financial institutions can manage risks to their own portfolios through working with their clients to reduce risks and impacts, and in doing so capture new opportunities for nature-positive products and services. This will have positive spill-over effects for the whole economy. Such products could include sustainability-linked bonds and loans for nature-positive activities. UK firms – both financial and real-economy - are well placed to capture opportunities and lead globally in the transition toward a more nature-positive economy given the strong regulatory environment already in place both within the financial sector and the real-economy. There is also a role in articulating to government the needs to set the right enabling environment for the transition.

7.1.3. Recommendations for enhancing analytics and scenarios

The project has demonstrated that significant benefits of strengthening collaboration between financial institutions and the scientific community, including toward the co-development of next generation scenarios and analytics. This project has benefitted significantly from close engagement between experts and financial institutions, in particular through informal engagement with the Climate Financial Risk Forum's Resilience Working Group. There is a need to continue and build such platforms for collaboration to maintain and strengthen the interface between FIs, data providers and the scientific community. In the UK, an example of a significant step towards this is the Integrating Finance and Biodiversity for a Nature Positive Future (IFB) programme, a £7M initiative co-led by NERC and Innovate UK to develop the solutions needed to embed the values of biodiversity in financial decision-making, and with an advisory board linked to the Green Finance Institute's G-FIN network. Looking ahead, Central Banks and supervisors might consider how existing successful fora, such as the Climate Financial Risk Forum could, for example, provide a central platform for collaboration. Such efforts need to be mirrored across countries and internationally. Such platforms should be open, inclusive and transparent and ensure that all products are fully peer-reviewed, in line with recommendations previously made on climate, e.g. Ranger et al. (2023).

An immediate priority could be the co-development of a preliminary benchmark set of nature-related scenarios for the UK, in collaboration with the scientific community, to support financial institutions to build technical capability and conduct the first analyses. The preliminary scenarios generated in this project could form the basis for an initial set of scenarios that could be shared openly, similarly to the CBES scenarios, to support firms. Our approach has been modular, developing components that others can use to build analytics and scenarios for their own processes. A set of co-produced scenarios could be refined iteratively over time with firms as a voluntary effort supported by the Climate Financial Risk Forum. Supervisory authorities should consider extending the design of the analysis to include mid to long term scenarios and impacts in the economy from biodiversity loss, in order to have a more comprehensive assessment of their impact on financial stability. The analysis should also be extended to include transition risk scenarios. An important potential element of this is agreeing on a taxonomy of risks and transmission channels for the financial sector (so that appropriate standards on different data types can be set) that could be explored and developed in partnership with the IFB.

Box 7.1: How the Nature-Related Risk Inventory could guide investments in data

There are repeated calls for 'investment grade data' to allow FIs and businesses to incorporate nature-related risks and opportunities into strategic decision-making. Such data are often described by a high quality of spatial and temporal coverage in order to inform on risk management and asset allocation decisions anywhere in the world. However, there is an important question of picking the right type of data that can adequately inform on risks. Commonly assembled data on biodiversity and ecosystem services (e.g. EU Commission, 2020) do not necessarily inform on risk. For example, there is a non-linear link between biodiversity and the resilient functioning of ecosystems (Oliver et al, 2015). There is first a need to understand the role that species play in delivering any ecosystem services (e.g. pollination, which is contingent on composition of pollinating insects and the spatial configuration of crops, pollinator resources and habitats; Gardner et al, 2020). Even after quantifying potential ecosystem service delivery, there is a further step to quantify the potential loss of service as a consequence of nature degradation (i.e. the risk of pollination deficit and impacts of agricultural yield and business viability). Such measures of risk can rarely be resolved using a single 'silver-bullet' data layer and require integration of socio-economic and ecological data into risk proxies, ideally with proper validation. One approach is to consider the risks in the NRRI. For each of these risks, appropriate indicator datasets can be assessed. For example, for the risk of wildfires causing direct damage to built infrastructure, data layers on biodiversity or even the ecosystem service provided by natural habitats as a buffer to wildfire are likely to be a very poor proxy for risk. Also needed are data on the configuration and composition of forests, the weather and hydrological conditions (e.g. soil/vegetation moisture), the location and vulnerability of built infrastructure (including redundancy in functioning) and the level of preparedness of local fire services. Developing an updatable set of indicators on different types of risk and their severity in specific locations is not a small task, but an essential one. Centralising such efforts (and making them transparent) could improve the quality and rigour of the underpinning science and data, and reduce redundancy in the efforts across different institutions. Hence, a live updated Nature-related risk inventory (NRRI) collated at both the national level and spatialised by geographic region or asset class is a valuable next step.

7.2. Next Steps

This project, conducted at pace over one year, has led to several innovations. But there have been limitations in the methods possible and still a substantial number of areas that need urgent progress if financial institutions are able to adequately assess and manage nature-related risks. A particular limitation has been the lack of counterparty-level data adequate for a full credit risk assessment, as well as the availability of granular information on the state of ecosystem services in the UK and globally, as well as quantitative evidence on the linkages between those ecosystem services and firm performance.

Future work that we would like to explore in Phase II to enhance the assessment includes:

- **Extend the analyses to include transition risks and opportunities,** building upon the initial transition exposure analysis presented in this paper and existing initiatives such as the Inevitable Policy Response scenarios.
- **Enhancing scenarios, including assessing medium-to long-term risks and considering more extreme but plausible outcomes.** The scenarios here should be considered as very conservative, in that while they go further than other studies in capturing complex risks, inevitably they do not capture all possible outcomes, including potential risks of catastrophic ecological regime change. Future analyses consider extending the design of the analysis to include mid to long term scenarios and impacts in the economy of biodiversity loss, in order to have a more comprehensive assessment of their impact on financial stability.

- **Working with financial institutions to incorporate counterparty-level data and assess portfolio-level dependencies and risks,** leading to much more granular analyses and specific recommendations on risk management actions that can be undertaken. As part of this, subsequent work should explore opportunities to integrate more granular sub-national ecological and other data, and explore the use of satellite and other data sources, as well as enhancing the assessment of risks and opportunities at firm level, including through analyses of firm-level disclosures.
- **Moving beyond banks to explore risks and opportunities to the wider financial sector,** in particular asset owners and managers and insurers.
- **Developing an open toolkit that can be used by financial institutions and others.** The modular approach taken in this study is suitable for turning into an open tool. An immediate next step is to publish the data generated in this study.

In addition, beyond understanding risk, moving toward informing responses:

- **Draw up sector transition pathways with firms and governments to guide business,** and provide guidance on how to construct credible nature-positive transition plans.
- **Assessing the nature-related impacts of portfolios** to understand how the collective impact across companies may degrade specific ecosystems of particular importance to the UK economy and thereby prioritise efforts to protect the most vital ecosystems and reduce the impacts that threaten them.
- **Advancing the underpinning modelling approaches,** including more sophisticated modelling of price and substitution effects, and exploring scenarios using non-equilibrium models and accounting for network effects, as in Ranger et al. 2022b.

7.3. Final reflections on advancing modelling of systemic nature-related risks

This study has demonstrated that severe climate change and ecosystem damage may trigger cascades of systemic risks that are difficult to model quantitatively with existing frameworks. A challenge is that model communities tend to be siloed by discipline or sector, with separate groups modelling, for example, tipping points in ecosystems, macroeconomic changes or financial contagion with little cross-talk between them. Integrated modelling is attempted in some cases, for example Integrated Assessment Models as used for IPCC assessments, though these are increasingly challenged by some in the climate science community for focussing on mid-range rather than tail-end risk (Sutton, 2019). They also focus on a subset of transmission channels and miss more complex pathways of risk transmission (Shepherd et al., 2018). For this reason, there is increasing advocacy for more simple but comprehensive modelling frameworks (e.g. storylines, narratives, causal networks, participatory systems mapping; Kunimitso et al, 2023; Oliver et al. 2021). These 'big-picture' approaches enable a better understanding of how risks can cascade across political, economic, social, technological, legal and environmental systems (i.e. 'systemic risks', Centeno et al. 2015), as a prior step to identifying the necessary focus for further quantitative model development. In other words, it is important to build the models to the problem and not to the available data.

Current modelling frameworks for understanding such risks are also inadequate because they fail to account for feedback processes between the economy and nature. Yet, recent approaches to couple models fail to account for key feedback processes between economic and financial systems and the environment. Past evidence shows these feedback processes do exist and have substantial impacts on environmental quality and finance. Coupled environment-economy models aiming to forecast risk over decadal timeframes should aim to reflect these key feedback processes, or risks will be severely underestimated. In particular, more recursive-dynamic approaches are needed to capture feedbacks from degradation in ecosystem services to economic agents. In addition, nature-related risks (NRR) should not be modelled independently since they are likely to co-occur.

This report and other nascent work in this area hopefully pushes the boundaries by considering compounding scenarios that integrate nature- and climate-related risk. However, it is clearly the case that such risks occur against the backdrop of a whole range of other global megatrends that generate geopolitical, technological and social risks, amongst others (e.g. UK Government Office for Science Trend Deck, 2021). It is important to consider how these wider sets of trends and risks can interact. For example, a recent UK project by the Government Office for Science and Technology considers interacting sets of 'chronic risks' in order to develop more resilience in government departments (GoS 2024). New approaches that explore how such diverse risks can interact to impact financial stability are urgently needed. New international initiatives such as the IPBES transformative change assessment (IPBES, 2024) and Accelerating Systemic Risk Assessment network (ASRA, 2024), as well as government Foresight capabilities may help in this endeavour.

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Annexes

This report document contains the following annexes :

Annex 1: Nature-Related Commitments of the 2023 UK Green Finance Strategy
Annex 2: The ENCORE Tool
Annex 3: Transition Risk Methodology
Annex 4: Evidence Base to Support the Narrative Scenarios
Annex 5: NiGEM Model
Annex 6: Specification of Quantitative Scenarios for NiGEM
Annex 7: Systemic Risk Component Analysis
Annex 8: Nature 'stress test' methodology

In addition there are several Supplementary Materials associated with this report, available as separate files:

Supplementary Material 1: Additional Technical Appendices, including NRR evidence statements and forward look, and all calibration data used in the NVaR analysis and NiGEM scenarios.
Supplementary Material 2: Associations between individual risks in the NRRI
Supplementary Material 3: UNEP-WCMC final report on dependencies analysis

Annex 1: Nature-Related Commitments of the 2023 UK Green Finance Strategy

Targets	International: Commitment to the **Kunming-Montreal Global Biodiversity Framework** UK: **Legally binding target** to halt the decline in domestic species abundance in England by 2030, and then increase abundance by at least 10% to exceed 2022 levels by 2042. "This target, together with other goals set out in our Environmental Improvement Plan published in Jan 2023, sets a clear direction that can help to make the UK a leader in private investment in natural capital"
Goals	2021: Government set a **goal to mobilise more than £1 billion per year of private finance into nature's recovery in England by 2030,** and at least £500 million of private finance per year by 2027. "We expect to see this finance made up principally of investment in nature-based solutions for carbon sequestration, flood risk management and water quality, as well as compensating for biodiversity and nutrient impacts (e.g. through Biodiversity Net Gain and Marine Net Gain)"
Other commitments	2021: Over 140 countries, representing 90% of the world's forests, signed the Glasgow Leaders' Declaration on Forests and Land Use (GLD) and committed to work collectively to halt and reverse forest loss and land degradation by 2030 while delivering sustainable development and promoting an inclusive rural transformation. Recognising the power and necessity of private finance in protecting forests and other ecosystems, GL Action 6 commits countries to facilitate the alignment of financial flows with international goals to reverse forest loss and degradation. We will work with UK financial institutions, starting with a series of Government-convened roundtables in 2023, to further tackle deforestation-linked finance. The UK government is **committed to supporting the development of markets for carbon and other ecosystem services in the UK,** guiding, and stimulating demand while also ensuring that they build trust and confidence. **UK's Finance Nature Recovery initiative**
Strategies/ Plans	This Strategy sets out the measures we are putting in place to mobilise that investment, including through Nature Markets Framework, published alongside GFS We will aim to **publish an investment roadmap by 2024** to support the nature-positive transition pathway for these sectors and will update them as policy develops. A number of sectors (such as agriculture, forestry, water, resources and waste) also have a critical role to play in delivering the goals set out in our Environmental Improvement Plan, in addition to the key contribution they will make to meeting our net zero target.
Policy/ Legislation	2021: Passed **the landmark Environment Act 2021,** putting environmental goals, such as reversing the decline in biodiversity, on a statutory footing. 2023: **Environmental Improvement Plan,** setting out how we will work with land managers, communities and businesses to deliver our environmental goals. 2023: **New Nature Markets Framework.** 2023: **Mandatory Biodiversity Net Gain,** which we legislated to introduce in Environment Act 2021, will establish a market for biodiversity units from Nov 2023. 149 Land managers who can create/enhance habitat on their land will be able to sell the units to developers needing to meet their obligations. 2023: committed to publish **Land Use Framework for England** in 2023, to inform how manage trade-offs between land uses as deliver ambitious climate and environmental goals, and provide clarity to the market The UK government has **set an expectation of a significant increase in the use of nature and catchment-based solutions** in the water sector, with companies and regulators working towards delivering these solutions as a matter of preference. As well as mandating **Biodiversity Net Gain** for developers and Nationally Significant Infrastructure Projects, we are aiming to make **Sustainable Drainage Systems (SuDS) mandatory** in new housing developments in 2024, subject to final decisions on scope, thresholds and process following consultation.

Regulatory, Standards, Disclosures	2022: The UK signed up to a **commitment in the Global Biodiversity Framework** to ensure the largest companies regularly monitor and disclose their risks, dependencies and impacts on nature. First government to fund and fully support the creation and progress of the Taskforce on Nature-related Financial Disclosures (TNFD). The UK government will explore how best the final TNFD framework, due to be published in September 2023, should be incorporated into UK policy and legislative architecture, in line with Target 15 of the GBF. The TNFD provides the main method of operationalising Target 15 and the UK government welcomes closer integration with the ISSB to **build a global baseline on sustainability reporting.** 2023: We are working with the Bank of England, the Green Finance Institute and other partners to quantify more effectively the potential UK financial exposures from nature loss and degradation. 2023: Given the importance of agriculture for our nature and climate change goals we have created the **Land, Nature, and Adapted Systems Advisory Group (LNAS)** as a sub-group to the G T A G to advise on sustainable agriculture and fisheries. It will also consider the role of infrastructure, including nature-based infrastructure, in delivering a resilient economy. **Nature investment standards**
Public Financial Institutions and Financing Vehicles and Schemes	The UK government is **investing £30 million Big Nature Impact Fund (BNIF),** a new blended finance impact fund managed by Federated Hermes and Finance Earth The **£50 million Woodland Carbon Guarantee** helps accelerate woodland planting and develop the domestic market for woodland carbon, by offering a price guarantee for verified carbon credits sold to the UK gov Our new **Environmental Land Managemen**t schemes are being designed to dovetail with private investment. In particular, we are supporting the bespoke **Landscape Recovery projects** to secure private funding alongside public funds in innovative ways. The UK government is providing four local authority areas with up to £1 million each to act as trailblazers in our **Local Investment in Natural Capital (LINC) Programme**
Data and Analytics	**Natural Capital and Ecosystems Assessment (NCEA)** **TNFD Nature-related data catalyst** UKRI including **Nature Positive Future programme**
Education, Skills and Research	The National Parks Partnership and National Association for Areas of Outstanding Natural Beauty to support capacity building of Protected Landscape bodies and increase pipelines of projects for private investment. Cover nearly 25% of land in England and are critical to attracting investment into natural capital, protecting habitats while enabling access for people. 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 £270 million committed to **agricultural and horticultural R&D** through the Farming Innovation Programme (FIP) to 2029, to enhance productivity, environmental sustainability and resilience in England's farming sectors Research focused on exploring options to **track private investment into nature** which we plan to publish shortly. We are looking at the feasibility of adopting some of the methods recommended. Supporting **86 innovative nature projects across England to explore ways of generating revenue from nature markets** and operate on repayable private sector investment, through the £10 million Natural Environment Investment Readiness Fund (NEIRF).
Goals	Scotland: Commitment to develop Scottish Government Interim Principles for Responsible Investment in Natural Capital
Strategies/ Plans	Wales: Contributing to the Global Biodiversity Framework by developing an action plan to deliver the 30x30 biodiversity target, including consideration of statutory biodiversity targets, ethical and transparent private investment in nature recovery.
Funding Commitment	Wales: Establishment of the Ministerial Portfolio for Climate Change in 2021, with an annual budget of over £2 billion to support Net Zero and tackle biodiversity loss in Wales.
Public Financial Institutions and Financing Vehicles	Scotland: Facility for Investment Ready Nature in Scotland (FIRNS), a £1.8 million investment readiness fund. Wales: Establishment of Sector and Regional Funds and Boards examples including Woodland Financing Group

International	
Goals and Commitments	2022: 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.
Regulatory, standards	2021: Secured support for launch of the **Taskforce on Nature-related Financial Disclosures,** now an international market-led taskforce with over 900 members representing over $20 trillion AUM
International Leadership and Policy/ influencing	Support **MDBs to align with the GBF** by implementing the MDB COP26 Joint Statement on Nature, including tracking and scaling up finance for nature. 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. 2022: UK co-launched a **Joint Donor Statement on International Finance for Biodiversity and Nature.** This statement by 14 countries included a commitment to collectively increase international biodiversity finance and align relevant international development flows commensurate with the ambition of the GBF. This means mitigating nature-related risks and impacts; assessing risks across financial systems from biodiversity loss; supporting recipient countries' transitions to net zero, nature positive economies; and increasing finance aligned with the mission to halt and reverse biodiversity loss by 2030.
Funding and related Commitments	ICF: ringfencing **£3 billion to protect and restore nature** 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. Leverage private investment through over £40 million of investment in the **Eco Business Fund** and the **Land Degradation Neutrality Fund,** which are dedicated to raising public and private capital to support sustainable land use projects and improve biodiversity. The UK is working with the **Global Innovation Lab** for Climate Finance to scope new support for projects in Latin America, including a potential thematic window to identify innovative financing solutions for high-integrity forests. 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. Programmes under the BPF include technical assistance to support blue bond development and funding for innovative financial tools that encourage private investment into marine nature-based solutions. The UK's **Biodiversity Challenge Funds** (the Darwin Initiative, Illegal Wildlife Trade Challenge Fund, and Darwin Plus) award grants to support the development and adoption of financial mechanisms to benefit biodiversity, people and the planet.
Capacity Building	The **Nature Positive Economy Programme** will be delivered in partnership with the U Development Programme's Biodiversity Finance Initiative (BioFin) and Financial Sector Deepening Africa. This supports governments, central banks, businesses, and financial institutions to integrate nature-related risks and opportunities into decision-making.

Annex 2: The ENCORE Tool

ENCORE knowledge base

ENCORE was first developed by Global Canopy, the UNEP Finance Initiative, and UNEP-WCMC with funding from the Swiss State Secretariat for Economic Affairs (SECO) and the MAVA Foundation. It is integral to this analysis.

The ENCORE dependency knowledge base outlines how different economic activities are potentially dependent on nature. It was applied within this analysis to assess how dependent the UK financial investment portfolio is on nature. Therefore, understanding the principles behind this knowledge base is important to understand the context of this work. It draws on scientific and grey literature, supplemented by expert reviews. Further detail on the methodology used for developing the ENCORE knowledge base can be found below and on the ENCORE website.

Principles behind ENCORE

In ENCORE, each sector's main production processes are linked to a series of ecosystem services on which they potentially depend for their continued operation. A full list of ecosystem services included in ENCORE can be found below. Each production process-ecosystem service link has a materiality rating, which can be Very High, High, Medium, Low or Very Low. These materiality ratings are based on available peer-reviewed and grey literature and expert input from sector practitioners. Therefore, each sector has its own 'dependencies profile' (i.e., the list of ecosystem services it potentially depends on and their associated materiality ratings).

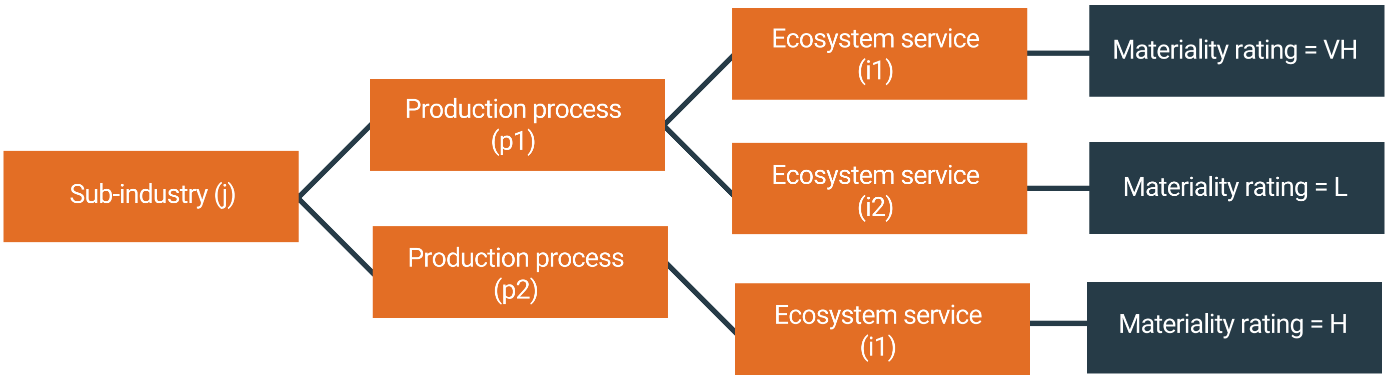


Figure: The structure of relationships in the ENCORE knowledge base. Each sub-industry is associated with several different production processes, which in turn are associated with one or more ecosystem services. VH = Very High; H = High; M = Medium; L = Low; and VL = Very Low.

The dependencies of economic activities on nature are often overlooked. ENCORE helps make these links explicit. For example, in the NACE Division of Electricity, gas, steam and air conditioning supply (D35), the required equipment and infrastructure need stable ground. Therefore, soil erosion and instability negatively impact the function of the whole energy generation sector.

In ENCORE, not all sectors are given the same dependency materiality rating for the same ecosystem service. For example, while both Oil & Gas Production in the energy sector and Brewers in Consumer Staples are dependent on the Flood and Storm Protection ecosystem service, the former has a very low (VL: Very Low) materiality rating for its dependence on the ecosystem service, whereas the latter has a medium (M: Medium) materiality rating for the same ecosystem service. This is accounted for in the analysis and means that when the combination is made with the financial data on exposures to different sectors from the dataset, the 'importance' of each ecosystem service will be weighted based on: 1) the materiality of the ecosystem services for all relevant sectors (using ENCORE); and 2) the amount invested by UK banks and insurers in those sectors.

Overview of ecosystem services

In ENCORE, ecosystem services are the links between nature and business. Each of these services represent a benefit that nature provides to enable or facilitate business production processes. Ecosystem services were classified according to the Common International Classification of Ecosystem Services (CICES), which comprises a five-level hierarchical structure, for example: Section (e.g., Provisioning), Division (e.g., Nutrition), Group (e.g., Terrestrial plants and animals for food), Class (e.g., crops), and Class type (e.g., wheat). Cultural ecosystem services were not included in the first iteration of ENCORE as they were not considered to be direct inputs or to enable production processes. The CICES framework has been simplified as below for use in ENCORE:

Ecosystem Services listed in Encore	Explanation
Animal-based energy	Physical labour is provided by domesticated or commercial species, including oxen, horses, donkeys, goats and elephants. These can be grouped as draught animals, pack animals and mounts.
Bio-remediation	Bio-remediation is a natural process whereby living organisms such as micro-organisms, plants, algae, and some animals degrade, reduce, and/or detoxify contaminants.
Buffering and attenuation of mass flows	Buffering and attenuation of mass flows allows the transport and storage of sediment by rivers, lakes and seas.
Climate regulation	Global climate regulation is provided by nature through the long-term storage of carbon dioxide in soils, vegetable biomass, and the oceans. At a regional level, the climate is regulated by ocean currents and winds while, at local and micro-levels, vegetation can modify temperatures, humidity, and wind speeds.
Dilution by atmosphere and ecosystems	Water, both fresh and saline, and the atmosphere can dilute the gases, fluids and solid waste produced by human activity.
Disease control	Ecosystems play important roles in regulation of diseases for human populations as well as for wild and domesticated flora and fauna.
Fibres and other materials	Fibres and other materials from plants, algae and animals are directly used or processed for a variety of purposes. This includes wood, timber, and fibres which are not further processed, as well as material for production, such as cellulose, cotton, and dyes, and plant, animal and algal material for fodder and fertilizer use.
Filtration	Filtering, sequestering, storing, and accumulating pollutants is carried out by a range of organisms including, algae, animals, microorganisms and vascular and non-vascular plants.
Flood and storm protection	Flood and storm protection is provided by the sheltering, buffering and attenuating effects of natural and planted vegetation.
Filtration	Filtering, sequestering, storing, and accumulating pollutants is carried out by a range of organisms including, algae, animals, microorganisms and vascular and non-vascular plants.
Flood and storm protection	Flood and storm protection is provided by the sheltering, buffering and attenuating effects of natural and planted vegetation.

Ecosystem Services listed in Encore	Explanation
Genetic materials	Flood and storm protection is provided by the sheltering, buffering and attenuating effects of natural and planted vegetation.
Ground water	Groundwater is water stored underground in aquifers made of permeable rocks, soil and sand. The water that contributes to groundwater sources originates from rainfall, snow melts and water flow from natural freshwater resources.
Maintain nursery habitats	Nurseries are habitats that make a significantly high contribution to the reproduction of individuals from a particular species, where juveniles occur at higher densities, avoid predation more successfully, or grow faster than in other habitats.
Mass stabilisation and erosion control	Mass stabilisation and erosion control is delivered through vegetation cover protected and stabilising terrestrial, coastal and marine ecosystems, coastal wetlands and dunes. Vegetation on slopes also prevents avalanches and landslides, and mangroves, sea grass and macroalgae provide erosion protection of coasts and sediments.
Mediation of sensory impacts	Vegetation is the main (natural) barrier used to reduce noise and light pollution, limiting the impact it can have on human health and the environment.
Pest control	Pest control and invasive alien species management is provided through direct introduction and maintenance of populations of the predators of the pest or the invasive species, landscaping areas to encourage habitats for pest reduction, and the manufacture of a family of natural biocides based on natural toxins to pests.
Pollination	Pollination services are provided by three main mechanisms: animals, water and wind. The majority of plants depend to some extent on animals that act as vectors, or pollinators, to perform the transfer of pollen.
Soil quality	Soil quality is provided through weathering processes, which maintain bio-geochemical conditions of soils including fertility and soil structure, and decomposition and fixing processes, which enables nitrogen fixing, nitrification and mineralisation of dead organic material.
Surface water	Surface water is provided through freshwater resources from collected precipitation and water flow from natural sources.
Ventilation	Ventilation provided by natural or planted vegetation is vital for good indoor air quality and without it there are long term health implications for building occupants due to the build-up of volatile organic compounds (VOCs), airborne bacteria and moulds.
Water flow maintenance	The hydrological cycle, also called water cycle or hydrologic cycle, is the system that enables circulation of water through the Earth's atmosphere, land, and oceans. The hydrological cycle is responsible for recharge of groundwater sources (i.e., aquifers) and maintenance of surface water flows.
Water quality	Water quality is provided by maintaining the chemical condition of freshwaters, including rivers, streams, lakes, and ground water sources, and salt waters to ensure favourable living conditions for biota.

Annex 3: Transition Risk Methodology

Underlying the analysis outlined in Chapter 2 are two sets of data. One set is national-level data for various indicators used to proxy transition risks in the WWF Biodiversity Risk Filter (WWF BRF) tool. The tool provides data for a variety of physical and reputational risks. As this analysis is focused on transition risks, the ratings for physical risk drivers (i.e. Land, Freshwater and Sea Use Change; Tree Cover Loss; Invasives; and Pollution) and all reputational risks (i.e. Protected/Conserved Areas; Key Biodiversity Areas; Other Important Delineated Areas; Ecosystem Condition; Range Rarity; Indigenous Peoples (IPs), Local Communities (LCs) Lands and Territories; Resource Scarcity: Food - Water – Air; Labor/Human Rights; Financial Inequality; Media Scrutiny; Political Situation; Sites of International Interest; Risk Preparation) are considered. Individual risk ratings provided by the WWF BRF are composed of one or more indicators, typically aggregated at the HydroSHED level 7. A comprehensive justification of those risks and their assigned indicators can be found here [WWF, 2023]. The standard WWF BRF methodology uses site-level data. National-level indicator values are published in their WWF BRF Country Profiles, which are used in this analysis to match the geographic specificity of the other dataset.

The second dataset used is financial data harvested from 2022 pillar 3 reports of 7 UK banks: Barclays, HSBC, Lloyds, NatWest, Standard Chartered, Santander UK and Nationwide. The data comprises banks' credit, loans and advances holdings split by national-level geography and industry (using the single-digit NACE sector classification). The total value of holdings analyses amounts to £1,107,902,000,000 (ca. £1.1 trillion) across 18 countries.

The WWF Biodiversity Risk Filter Assessment

To understand the methodology used for this analysis, it is worth briefly considering the methodology deployed by the WWF BRF. The WWF BRF tool seeks to provide insights into the exposures to nature-related financial risks at the asset level. Risks are split between physical (which include both physical and some transition risks, see 'Data' section) and reputational risks. The risk rating (the 'scape risk') is calculated as the arithmetic mean of the industry materiality rating and the site-level risk value. The industry materiality rating is the estimated average impact of an economic activity on a given factor (i.e. impact of paper mills on pollution), which is informed by a robust literature review. The site-level risk value is informed by one or multiple indicators and their respective datasets. Both industry materiality ratings and site-level risk values are ordinal data on a scale of 0 to 5, where 1 indicates very low risk and 5 indicates very high risk. Once the scape risk for individual assets is calculated, the value-weighted average scape risk of each of these assets is aggregated to the company level. After which, the value-weighted average of scape risk of all companies in a portfolio can be aggregated. It should be noted that assets, companies and portfolios do not possess a single scape risk rating, but instead a rating for each nature-related transition risk, such as tree cover loss, pollution, etc. The methodology also has an in-built capability to calculate value chain risks, but in this instance, we limit ourselves to first-order risks to maintain simplicity in our analysis.

Calculating national-level exposures using the foundation of the WWF BRF methodology

Though the WWF BRF provides insights on the exposures to nature-related risks at the asset-, company- or portfolio level, it does not make a judgement call on significant or insignificant exposures. Despite leading to more conservative estimates, this is an important step when carrying out analyses at the portfolio- or sector-level for it highlights priority areas for action. Without delimiting exposures as significant or insignificant, such analysis would find that 100% of portfolios are somewhat exposed to at least one nature-related risk. For this reason, the analysis adopts the exposure approach taken in high-level macroeconomic nature-related financial risk analyses carried out by central banks around the world (e.g. van Toor et al., 2020; Svartzman et al., 2021, etc.), which defines a significant exposure as any activity rated High Risk or Very High risk. A further deviation from the approach taken in the WWF BRF pertains to aggregation. In the WWF BRF, competing scape risks within a company or a portfolio are averaged.

However, as Svazrtman et al. (2021) and subsequent analyses point out, this assumes a degree of substitutability, which is not necessarily true (i.e. the impact of a damaging economic activity can be substituted by another economic activity within the same company). Instead of taking the average scape risk across activities, we instead take the maximum value for a given risk across activities within a portfolio (it should be noted that the impact of this decision is minimal in any case). Finally, instead of using site-level indicator data, we use a dataset of indicator values aggregated at the national level to match the geographic specificity of the financial dataset.

To summarise, the step-by-step process of the methodology used herein is outlined below:

- Manually match the sector disaggregation between the WWF BRF industry materiality ratings and the financial data – where BRF industries have to be aggregated (e.g. agriculture (animal products) and agriculture (plant products)) the maximum value per risk is taken. Diagram X shows the final table.
- Match the updated materiality ratings with the financial holdings of each bank using the sector.
- Calculate aggregate exposure – sum together all holdings that are significantly exposed (4 or above) to at least one nature-related transition risk and divide by the total portfolio.
- Calculate aggregate exposure by risk – sum together all holdings that are significantly exposed (4 or above) to each specific nature-related transition risk and divide by the total of the portfolio.
- Repeat Step 3 and Step 4 for each bank.

	Pollution	Tree Cover Loss	Protected/Conserved Areas	Indigenous Peoples (IPs); Local Communities (LCs) Lands and Ter.	Land, Freshwater and Sea Use Change	Key Biodiversity Areas	Other Important Delineated Areas	Ecosystem Condition	Media Scrutiny	Labor/Human Rights	Political Situation	Sites of International Interest	Invasives	Range Rarity	Financial Inequality	Risk Preparation	Resource Scarcity: F
Agriculture, forestry and fishing	5	5	5	5	5	4	4	4	5	4	3	3	3	3	2	2	3
Manufacturing	5	5	5	5	5	4	4	4	5	4	3	3	3	3	2	2	2
Construction	5	5	5	5	5	4	4	4	4	4	3	3	2	3	2	2	1
Mining and quarrying	5	5	5	5	5	4	4	4	5	4	3	3	2	3	2	2	2
Electricity, gas, steam and air conditioning supply	5	4	5	5	5	4	4	4	2	2	3	3	2	3	2	2	1
Transport and storage	4	5	5	5	5	4	4	4	1	2	3	3	3	2	2	2	1
Water supply	2	1	3	3	1	2	2	2	5	2	2	2	3	2	2	2	1
Accomodation and food service activities	2	3	1	1	1	1	1	1	3	4	3	3	3	2	2	2	3
Administrative and support service activities	1	3	3	3	3	3	3	3	3	3	2	2	2	2	2	2	1
Arts, entertainment and recreation	1	3	3	3	3	3	3	3	3	3	2	2	2	2	2	2	1
Education	1	3	3	3	3	3	3	3	3	3	2	2	2	2	2	2	1
Financial and insurance activities	1	3	3	3	3	3	3	3	3	3	2	2	2	2	2	2	1
Other services	1	3	3	3	3	3	3	3	3	3	2	2	2	2	2	2	1
dministration and defense, compulsory social security	1	3	3	3	3	3	3	3	3	3	2	2	2	2	2	2	1
Real estate activities	1	3	3	3	3	3	3	3	3	3	2	2	2	2	2	2	1
Information and communication	2	5	3	3	3	2	2	2	1	2	2	2	2	2	2	2	0
Human health services and social work activities	5	1	3	3	1	2	2	2	1	2	2	2	0	1	2	2	1
Wholesale and retail trade	4	1	1	1	1	1	1	1	3	2	1	0	2	0	2	2	1
Professional, scientific and technical activities	2	1	1	1	1	1	1	1	3	2	1	0	0	0	2	2	0

Graph X: Table of industry materiality ratings for one-digit NACE sectors using the maximum value at point of aggregation.

Limitations

This analysis is limited to potential risks and not actual risks – the analysis only takes into consideration the probability of threats occurring and the extent to which a bank is exposed to these threats via its holdings. It does not consider a critical third dimension of risk, which is the actual vulnerability or preparedness of an asset or company to a specific threat.

The BRF methodology does not provide disaggregated materiality ratings for a multitude of professional sectors, such as real estate, finance and other professional services, IT, education etc.

The data used to inform this analysis has a risk of omission where either certain holdings are not captured in the financial data or certain nature-related transition risks are not identified.

In aggregating BRF data to the national level and into an ordinal scale of five categories, nuance in the distribution of risks is lost. The analysis of nature-related transition risks is only as strong as the geographical financial data underlying it. Some banks have elevated allocations in small countries such as Guernsey, Jersey, and Luxembourg where it is likely investments are transferred into other geographies – the same goes for activities and the large proportion of holdings classified into the financial and insurance activities.

Annex 4: Evidence Base to Support the Narrative Scenarios

Table A4.1: Evidence Base to Support UK Domestic Scenario

Chronic	
Water pollution and water scarcity	Statistics on water quality in the UK suggest only 14% of rivers and lakes in England are achieving good ecological status - largely unchanged from 16% in 2009 - and 0% good chemical status[1] (Environment Agency and Natural England, 2023). Key issues impairing achieving good status of water bodies include agricultural runoff (40%), wastewater and sewage (36%) and urban pollution (18%) with microplastics not routinely monitored (Environment Agency and Natural England, 2023). In order to achieve the Water Framework Directive target of 100% water bodies achieving good status, investment is required. Over-abstraction and pollution of waterways result in £5.3B investment over 2023-2027 to improve water quality and security (EA,2022), equivalent to 0.1% annual public expenditure (1,042 Bill. 2022/2023) (HMT,2023). These costs increase household and industry costs. Due to increasing pressures on the water system, daily public water supply is expected to increase by at least 29% (4 billion litres at least vs 14 today) by 2050 in England (DEFRA, 2023b). Around 20% of treated water in the UK is lost due to leakage (OFWAT, 2022) with highly populated areas like London and the West Midlands surpassing 22% (DEFRA, 2023b). In England over-abstraction affects 15% of rivers and 27% of groundwater bodies (DEFRA, 2023b). Victorian-era infrastructure - including a Victorian-era ~150 year old sewage network (designed for 4M people and currently servicing 9M people), coupled with increasing pressures from population growth and climate change, are resulting in increasing pressures and overuse of storm overflows (DEFRA, 2023b).Sewage discharge into the sea and waterways from storm overflows is currently at a level considered to be 'unacceptable' in the UK (in 2020, over 400,000 sewage discharges, totalling over 3 million hours; DEFRA, 2022c). This affects public health via the consumption of contaminated drinking water, aerosolization of pathogens, food-chain transmission, and direct contact during recreation (Sojobi and Zayed, 2022). Impact on labour availability, e.g. contamination of shellfisheries resulting in increase in norovirus infections, which in 2009 resulted in [1] "Chemical status excluding ubiquitous, persistent, bioaccumulative, toxic substances (uPBTs): 93% at good status" for rivers and 100% for lakes. uPBTs include mercury and other substances (Environment Agency and Natural England, 2023).

Chronic	
Water pollution and water scarcity	between 14,593 and 30,160 days working days lost (Hassard et al, 2017); reduction in access to open water swimming also has the potential to cause a decline in mental health (Overbury et al. 2023). Decline in domestic tourism (market risk, credit risk); one study estimated that reduced water quality resulted in reduction in recreational value of water bodies equivalent to £9.65–33.54 million per year, and net economic losses to tourism of £2.94–11.66 million per year (Pretty et al, 2003). Costs to water companies for improvements to sewerage system, passed on to customers in form of rise in bills (DEFRA, 2022c); additional financial impact from legal costs of EA criminal investigation into breaches of environmental permit conditions (EA, 2023b). Major litigation against water companies for failure to protect water quality causes implications for UK pension schemes (e.g. for Thames Water shareholders) and microeconomic impacts on pensioners.
Soil health decline	Annually, soil degradation costs (0.9-1.4 Bill. in England and Wales) represent 8-12.5% of UK GVA from agriculture (DEFRA, 2022a). Soil erosion is projected to increase between 13-22.5% by 2050 in the EU and the UK (Panagos et al. (2021)). Assuming soil degradation costs increase by 22.5% by 2050 (equivalent to 0.75% annually for 2023-2050), 0.09% GVA from agriculture would be lost annually. From a UK perspective, the overall drier conditions in East Anglia, and lack of crop cover as a result of stunted or failed crops, may lead to soil removal via windstorms, comparable to the dustbowl in America in the 1930s. The occurrence of increasingly more prevalent thunderstorms, on the largely uncovered soils, will further increase the loss of fertile topsoil due to flash floods, whereby the soil organic matter and nutrients will be washed away into streams, with further implications for water quality. Rising temperatures will cause accelerated breakdown of soil organic matter, with negative implications for soil nutrient quality and soil structure. The cascade of events described above will have detrimental direct and indirect effects on the agricultural production and processing part of the UK food supply chain, as well as other parts of the chain. Impact is chronic causing reduced wheat yields even in the face of agricultural innovation. Negative effects of air pollution will further reduce crop yield. Price rises of chemical fertilisers also exacerbate impacts leading to marked price increases of cereals on the world market. Impacts are gradual and UK farmers could be kept in business through business adaptation and with re-alignment of agricultural subsidies. However, significant, widespread damage to soils could lead to major impacts on agriculture-related industries/investors.
Land-Use and Rising Flood Risk	Land use change (loss of wetland habitats and more compacted agricultural soils) exacerbate effects of intense rainfall events and rising sea levels causing flood-induced damage to residential and commercial properties and infrastructure including transport networks, water, electricity and gas supplies and telecommunications (CCRA3, 2021 - Flooding). England has lost around 90% of its freshwater wetlands over the last 100 years (EA, 2019) due to intensive agriculture, aquaculture, housing development and industry. This increases flood risk, further compounded by river management practices resulting in the loss of floodplains (Entwhistle et al, 2019). The estimated value of flood mitigation by saltmarsh in 2019 was £62 million in England and £9 million in Wales (ONS, 2022). Flooding has been shown to have significant negative impacts on mental health amongst those affected, including increased risk of anxiety and PTSD (PHE, 2020b). Whilst historically flooding has caused an increase in insurance claims and corresponding rise in premiums, the effects of this have been mitigated in recent years through the implementation of the Flood Re scheme (HoC, 2023a). There is concern however that the long-term effects of such a scheme are likely to be counter-productive (OECD, 2020). The impact of flood risk on the market value of UK property is not yet proven (Lamond et al, 2010). SMEs have been shown to be particularly vulnerable to flooding (Skouloudis et al, 2020). A case study of severe weather and flooding in Cumbria in 2015 demonstrated severe negative impacts on local tourism, with 89% of business affected and average costs of £136,400 from repairs and loss of trade (Cumbria Tourism, 2016).

Chronic	
Air pollution and biodiversity loss	According to the Global Burden of disease (GBD) study, air pollution caused 5.5 million premature deaths globally in 2013 (OECD, 2016) rising to 6.7 million in 2019 (GBD, 2020) - equivalent to a 3.3% annual increase- surpassing the lower estimate of projected deaths by 2060 (6-9 mMillion, (OECD, 2016)). By improving air quality, 17,000 premature deaths could be prevented in the UK annually (CBI, 2020), out of a workforce of 32,9 million (ONS, 2023b). Effects on respiratory health and mental health require increased public health spending. Air pollution is the "single greatest environmental threat to health in the UK" (EA, 2023c). Annual cost of health damages from PM2.5 in 2019 were estimated as 2.6% GDP equivalent in the UK (World Bank, 2019). NHS and social care costs due to PM2.5 and NO2 combined (42.88 million in 2017) are projected to quadruple by 2025 in England (PHE, 2018a). Market impacts from welfare costs due to air pollution in the OECD are projected to increase from 90 to 390 billion USD. between 2015 and 2060 (equivalent to a 3.3% annual increase) (OECD, 2016).Biodiversity loss can result in mental distress (Cianconi et al., 2021). Ongoing loss of biodiversity through habitat loss, invasive species, pollution and climate change, together with a highly urbanised UK population, leads to fewer opportunities for people to engage with nature (Miller 2005). Loss of biodiverse green spaces are associated with mental health impacts (e.g. anxiety, depression and apathy) (PHE, 2020a). This, in turn, reduces motivation and capacity to protect nature, leading to 'vicious cycles' of biodiversity decline and poor mental health (Oliver et al., 2022). Effects on respiratory health and mental health lead to reduced workforce in terms of availability and productivity. By improving air quality in the UK, 3 million working days would be gained (CBI, 2020), approximately 10% of total working days lost (WDL) to illness (HSE). Average days lost per worker increased by almost a quarter in the last decade: to 1.42 (average 2019/2020 and 2021/2022) from 1.15 (10 year average 2008-2019) (HSE).Global annual WDL due to air pollution are expected to increase from 1.24 in 2010 to 3.75 billion in 2060 (2.2% annual equivalent increase) (OECD,2016).

Acute	
Severe heatwaves and drought	**a.** Reduction in yields in UK and N. Europe (reduced agricultural productivity). Out of 17.2 megahectares (Mha) agricultural land in the UK, 2 million (11.6%) are at risk from soil erosion and 4 million (23.2%) are at risk from soil compaction (DEFRA, 2022a). Crops contribute 36% to agricultural sector production (11.2 billion GVA total) (DEFRA, 2022a). Following an extreme weather event, yield losses on degraded land can decrease by up to 40% and, if yields decline by 27% per cent for two consecutive years, then a typical UK cereal farming business becomes unprofitable (CISL, 2020 and references therein). **b.** Drought and heatwaves reduce water availability in the UK and Northern Europe, causing an increase in public expenditure/ household costsProjections estimate supply-demand water deficits due to droughts and heatwaves in several regions in England and Wales by 2050 (HR Wallingford, 2020). Emergency measures (tankers) to ensure water supply total 0.13% of public expenditure annually. **c.** Large air pollution and heat impact on major cities (health impacts) with reduced overall productivity and labour productivity, It is estimated that 7 in 10 people will live in cities by 2050. Urban heatwaves are directly linked to an increase in air pollution (Ulpiani, 2021) and the number of cities exposed to extreme temperatures/heatwaves will also nearly triple by 2050 (C40 Cities, 2023). Total costs of heat related morbidity in the UK could increase between 84%-114% during 2020-2050 (Watkiss et al., 2021); equivalent to 2-2.5% annually. Wildfires in other countries could also exacerbate air pollution, with 20% of all particulate matter pollution from all sources currently entering the UK atmosphere coming from other countries (DEFRA, 2023g).

Acute	
Major wildfires	**a.** Capital stock damage. Global extreme fires are expected to increase by up to 14%, 30% and 50% in 2030, 2050 and 2100, respectively (UNEP, 2022). In 2020, the total social and economic cost of fire in England totalled £12 billion, with £2 billion corresponding to property damage (Home Office, 2023c). Insurer risk premia for the low risk category increased between 4.5% and 52.8% over 2003-2018 in California (0.3% to 2.9% annual equivalent, 1.6% average (RFF, 2022, Table 1)). **b.** Acute air pollution impact from major wildfires. In the UK, a dramatic increase in the occurrence and severity of wildfires occurred in the years 2018, 2019 and 2020; this trend is mirrored in countries of a similar latitude such as Germany and Denmark (Belcher et al., 2021). During the 2018 wildfire in Saddleworth Moor, 4.5 million people were exposed to 'harmful levels of PM2.5' (Kovats et al., 2021), equivalent to 6.7% of the population of England. A recent study on annual labour impact effects of wildfires in the US, estimates a reduction of 0.1% in per capita earnings per each smoke day which aggregated to almost 2% of "U.S. annual labour income ($125B in 2018 dollars) per year on average between 2007–2019." (Borgschulte et al., 2023, p. 2).Major wildfires damage forestry stocks reducing productivity and fire sale of forestry assets (market risk). Wildfires cause impacts on tourism and collapse of service sector SMEs. e.g. wildfires cause 0.11–0.18% decline in GDP in Southern Europe (Meier et al, 2023). Recurrent wildfire risks in certain regions increase insurance premiums and impact property market - decrease in value of assets (market risk); increase in insurance claims (underwriting risk) (ABI report 2023). This interacts with recurrent heatwaves that cause proportion of UK housing and commercial property to become unusable; drought causes additional damage to property from subsidence (CCRA3, 2021 - Housing).

Table A4.2: Evidence Base to Support International (supply chain) Scenario

Chronic	
Soil (land) Degradation	Soil degradation affects between 20-40% of global land area and 52% of agricultural land (UNCCD, 2022 and references therein). Drivers of land degradation include: land management (cropland and agroforestry, grazed lands, native forest and tree plantations), resource extraction (non-timber products, energy and industry), fire, invasive species and urbanisation / infrastructure development (IPBES, 2018). Land degradation and climate change (mutually reinforcing factors) are projected to decrease global agricultural yields by 10% average (up to 50% in some regions) and likely to result in migration (IPBES, 2018). A future global food scenario to 2050 analysis projected food prices as likely to increase significantly particularly when considering production and consumption costs (FAO, 2018).
Soil Salinisation	Soil salinisation is driven by vegetation removal, heavy rainfall [AV1] and irrigation with saline waters combined with high evapotranspiration rates, and affects almost 9% of global land area. There are large negative impacts on ecosystem services including: provisioning (freshwater, crops, livestock, fuel and fibre crops, wild animal and plant foods), regulating (water regulation/ purification, soil erosion) and cultural. Hotspots in China, India, US, Australia, Argentina, Pakistan, Sudan, countries in Central and Western Asia and the Mediterranean coast (IPBES 2018). For example, in Southwest Australia – increasing soil salination in this major wheat belt is caused by water extraction and vegetation removal. Whilst the soil in Australia natural contains salt, the replacement of native vegetation with intensively farmed arable and pasture crops, and increased irrigation has left thin top-soil levels with irreversibly high levels of salt. In Australia, around 5.7 million hectares of land is classed as having 'high potential' for salinisation, expected to rise to 17 Mha by 2050.

Chronic	
Amazon Regime Shift	Amazon Regime Shift Overexploitation of land and climate change lead to gradual regime shift of forestry in the Amazon, with significant impacts.Local ecological regime shifts driven by changing land use and intensive agriculture impacting forestry and agriculture essential for global dynamics of carbon, climate, and water. As such, the dieback of the Amazon rainforest, or irreversible transformation into dry savannah, is considered an ecological tipping point, along with the collapse of Arctic Sea ice, boreal forest, and Permafrost, amongst others (Lenton et al., 2008; IPCC, 2021). However, the Amazon has been in decline in terms of carbon sink, forest area, and biodiversity for decades (Cox et al., 2004; Rammig et al., 2010; Huntingford et al., 2013; Brienen et al., 2015; Boulton, Lenton and Boers, 2022).The main drivers contributing to the dieback are changes in land-use activity, agricultural expansion, forest fires, climate change, and deforestation, and they are operating simultaneously and producing non-linear effects (Malhi et al., 2008; Nepstad et al., 2008; Nobre et al., 2016; Lapola et al., 2023). These drivers particularly amplify the intensity and frequency of regional droughts and significant reduction in rainfall (Cox et al., 2004; Zemp et al., 2017; Boulton, Lenton and Boers, 2022). In turn, extreme droughts and changes in rainfall directly contribute to carbon losses, vegetation loss, and biodiversity degradation (Barlow et al., 2016; Berenguer et al., 2021; Lapola et al., 2023). In terms of economic implications, the dieback scenario could significantly increase the social cost of carbon, from USD 15 to between 52-116 per tCO2 (Cai, Lenton and Lontzek, 2016; Dietz et al., 2021). Similarly, literature estimates that the economic impact from Amazon rainforest degradation to be upward of three trillion USD by 2050, covering sectors including agriculture, fisheries, transport and livelihood, energy and infrastructure, ecosystem services, cities and migration, and health (Lapola et al., 2018). These sectors are directly linked to their counterparts in the UK, which could impact the country's national economy and the financial system. For example, the rising demand for agro-industrial commodities (e.g., biofuel, palm oil, soya) puts incentives for cropland expansions in the Amazon (Nepstad et al., 2008). The dieback scenario could therefore lead to critical supply chains interruptions (i.e., throughout food value chains) and thus changes in availability and prices of agricultural assets and other related commodities in the UK.
Impacts on key concentrated commodity supply chains	Coupled with agro-ecological degradation (soil erosion, soil degradation and increased runoff) caused by increased intensive agriculture practices, natural rubber production remains highly vulnerable to nature drivers and climactic shifts (CGIAR, 2020). As a key input into the automotive industry, disruptions to the natural rubber supply chain may create outsize global inflationary pressures.
Pollinator decline	Pollination plays a critical role in over 75% of 'leading types' of global crops including most nuts, fruits and seeds (IPBES, 2016; Potts et al., 2016). Studies have documented not only the dependency of these crops on pollinator activity but also the increase in yields associated with healthy pollinator populations.2 They also provide essential services by pollinating plants that eventually become medicine, timber, fibres for textiles, biofuels, and wild plants. Decline in pollination has been documented in North America and the UK (Koh et al., 2015; Powney et al., 2019) as well as local declines in other regions (IPBES, 2016). Direct drivers of pollination decline include: "land-use change, intensive agricultural management and pesticide use, environmental pollution, invasive alien species, pathogens and climate change" (IPBES, 2016, p. xxii). Based on global literature, estimated value of pollinators to crops in the UK is £0.5 billion per year, but expected to be an underestimate4, and the UK also relies upon imports of food and materials from around the world impacted by pollinator loss. In 2021, 93% of the vegetables consumed in the UK were produced either domestically or the EU, whereas fruit has much more diverse origins ranging from the EU to Africa to South America5. The situation for pollinators is likely to become more dire under business-as-usual climate and nature loss scenarios. Agriculture and climate change combine and are associated with pollinator reductions, especially in tropical forests that supply so much of the produce on which the UK relies.

Chronic	
Fisheries	The split between catch fisheries and aquaculture has changed from 80/20% in 1990 to 51/49% in 2020 (FAO, 2022). The fraction of global fisheries stock fished unsustainably increased from 10% in 1974 to 35.4% in 2019 with regional values as high as 63.4% in the Mediterranean and Black Sea and 66.7% in the Southeast Pacific (FAO, 2022). Drivers of fisheries decline include: pollution, overfishing and poor management (FAO, 2022). In the UK, overfishing affects half of the most important stocks (OCEANA, 2023). As a net importer of fish (Marine Management Organisation, 2023), overexploitation of fisheries would impact on commodity imports and prices, negatively impacting the UK. Mangrove removal reduces habitat for fish nurseries, and pesticide pollution can cause fishery collapse7. Fishery collapse is the most directly correlated to economic impacts in the UK, though the spillover effects from mangrove and coral reef degradation will have severe implications for the UK.
Eutrophication	Nutrient deposition is not confined to international borders and eutrophication is rising around the world, especially in coastal and fresh waters15. The UK's food supply relies on imports, both fisheries and produce, that are and will continue to be affected by nutrient pollution. As livestock production rises in places like the Amazon to meet global demand for meat, animal waste can contribute to nutrient deposits and algal blooms that impair downstream food production, recreation, and tourism industries on which many countries rely heavily for economic incomes. Freshwater eutrophication and declining water quality can also trigger government-imposed austerity measures and industry restrictions in the UK's trading partners, as is currently happening in the Netherlands16, and these sorts of crisis responses could rise as water quality continues to be threatened. All of these factors will interact to present significant risk to the UK financial system.
Biofuels and Impacts on Oil Prices	Biofuel production worldwide is currently on an upward trend from 180,000 to 1.9M oil barrels equivalent in 2000 to 2022 respectively (11% average annual equivalent) (Statista, 2023). The IEA forecast total global biofuel demand to increase by over 20% in 2022-2027 (IEA, 2022). However, with finite land available, biofuel competes with food production (Searchinger and Heimlich, 2015) and food insecurity could lead to reversal of biofuel mandates (Boucher, 2022). Oil prices are historically highly variable but show upward long term trends, which could be exacerbated by marked decreases in biofuel production (Macrotrends, 2023).

Acute	
Food prices	The food price index reached an all-time high in 2022 (68% above 1990-2022 average) including cereals, meat, dairy and oils prices (authors calculation based on FAO Food Price index, 2023). Global food security has had a downward trend since 2019 with affordability falling by 4%, affected by an increase in length and frequency of shocks – COVID-19, Ukraine war- and high input costs (The Economist Group, 2022). Africa is severely affected with six out of ten countries with the weakest Global Food Security Index (GFSI) (The Economist Group, 2022) and more than 50% of hunger hotspots -including the 4 hotspots of higher concern- located in the region (WFP and FAO, 2023).
Multiple Breadbasket Failure	Global food insecurity has risen since the Covid-19 pandemic; a recent report by the UN states that the proportion of the world population facing chronic hunger in 2022 was about 9.2 percent, compared with 7.9 percent in 2019 (FAO, 2023). The UN states that the global food system relies on a series of dependency relationships which are vulnerable to crises such as conflict or pandemic; these include dependencies on food exports, food imports, fertilizers or on a single food group such as wheat (UN, 2022), all of which are vulnerable to the disruption of global supply chains. The same report states that conflict, rather than lack of supply, is the primary driver of global food insecurity; the invasion of Ukraine by Russia resulted in wheat price increases of almost 70% (UN, 2022). Food price volatility is associated with food riots and civil unrest, which has an adverse effect on economic activity, reducing GDP by an

	average 0.2 percent, rising to 1% for a significant unrest 'event' (Hadzi-Vaskov et al, 2023). These effects can be mitigated via government financial assistance schemes as were instituted during the Covid-19 pandemic, but these are costly (Fontan-Sers and Mazhar Mughal, 2023).Literature points to evidence of rising risks of multi breadbasket failure from a combination of changes in land-use and water cycles linked with human-induced changes and climate change (Gaupp et al. 2020; Mehrabi and Ramankutty, 2019); Janetos et al. 2017; Hasegawa et al. 2022). Multi breadbasket failure would have knock-on effects globally via increasing food insecurity through higher prices which could result in violent conflict (Delgado et al., 2021).According to the FAO Food Prices indices, the maximum historical 2-year shocks in global food prices were 62% (2006- 2008) and 40% (2020-2022) and the maximum annual shocks were 30% (2006-2007) and 28% (2020-2021) (authors calculation based on FAO Food Price index, 2023). Changes in global average production of the main cereal crops of over 30% for one year have been attributed to climate change (Lobell and Field, 2007), albeit the literature underlines the uncertainty in this. In addition, projections show a non-linear relationship between an increase in yield loss risk and drought severity (Leng and Hall, 2019).
Fiscal issues and financial instability (impact on investment and risk premia globally)	In 2023, the IMF reports several tests to the resilience of the global financial system have raised financial stability risks (IMF, 2023a). In addition, fragmentation (financial and economic) resulting from geopolitical issues could further aggravate these risks (IMF, 2023a). Global GDP growth is expected to decrease by 0.5 pp in 2023 and 2024 vs 2022 (3.5% vs 3%) (IMF, 2023b). For the UK in particular, real GDP is expected to decrease from 4.1 in 2022 to 1 in 2024 (IMF, 2023b). High inflation could persist due to higher commodity prices resulting from extreme weather shocks and escalation of geopolitical issues (Ukraine) (IMF, 2023b). The Ministry of Defense in their 2050 outlook, suggest the UK's higher vulnerability to economic warfare and financial crisis given the size of their financial sector (MoD, 2018).
Geopolitical instability and trade wars	The MoD in their Global Strategic Trends 6th report suggest that deliberate limiting of scarce resources by countries could result in heightened geopolitical tensions (MoD, 2018). These conflicts could escalate over shortages of critical minerals, food or water and there may be synergistic effects of these problems. For the former, it is estimated that at current global consumption rates we have only 4, 9 and 13 years left of Indium (used in LCD screens), silver (catalytic converters), and antimony (drugs) respectively (MoD, 2018).There are expected global increases in demand for water for crop irrigation (40% predicted increase by 2050 compared with 2010 levels (UN, 2018), in which the manufacturing sector's demand for water could be 400% higher by 2050 than in 2000 (MoD, 2018). Groundwater provides drinking water to at least 50% of the world's population, but a third of the Earth's largest aquifers are already being drained at an unsustainable rate. By 2050, groundwater extraction could be 39% higher than current levels (UN, 2018). Water scarcity affects roughly 40% of the world's population and, according to predictions by the United Nations and the World Bank, drought could put up to 700 million people at risk of displacement by 2030 (UN Drought Initiative). Research suggests water-related violence is increasing over time (Levy and Sidel, 2011), driven by increasing water demand worldwide exacerbated by climate change.

Table A4.3: Evidence Base to Support Health (AMR-pandemic) Scenario

Chronic	
AMR mortality/ morbidity	AMR is a significant threat to humans, animals/livestock, and the environment; the WHO has declared AMR as one of the top 10 global public health threats facing humanity today (WHO, 2020). AMR is caused by the overuse and misuse of antimicrobials, including antibiotics, antiseptics and antifungal agents, which results in mutations in the microorganisms which cause diseases; they become resistant, resulting in infectious diseases which are more difficult to treat and easier to spread (WHO, 2023). This leads to an increase in AMR-related mortality and morbidity, which puts a substantial pressure on the healthcare system through increased and prolonged admissions and the costs of medication (Dadgostar, 2019). Currently, across the globe, approximately 700,000 individuals lose their lives because of drug-resistant infections each year (AMR Review, 2016); the highest rates of AMR-related mortality are found in western sub-Saharan Africa (Murray et al. 2022). After declining during the pandemic, resistant infections in England rose by 4% in 2022 (UKHSA, 2023). Research suggests that antimicrobial resistant bacteria double the chances of developing a serious health issue and triple the chances of death (Cecchini et al, 2019). An additional and often overlooked threat is the emergence of pathogenic fungi such as azoles that are resistant to antifungal agents: 'the global mortality rate for fungal diseases now exceeds that for malaria or breast cancer and is comparable to those for tuberculosis and HIV' (Fisher et al, 2018). AMR is on the rise; between 2000 and 2015, antibiotic consumption, expressed in defined daily doses (DDD), increased 65% (21.1–34.8 billion DDDs), and the antibiotic consumption rate increased 39% (11.3–15.7 DDDs per 1,000 inhabitants per day) (Klein et al. 2018). By 2030, the global human consumption of antibiotics is forecast to rise by more than 30%, at the current rate rising up to 200% (HMG, 2019). It is estimated that by 2050 AMR could directly and indirectly be responsible for up to 10 million deaths per year globally if strong and effective action is not taken (United Nations Environment Programme, 2023; Chokshi et al, 2019; Laxminarayan et al, 2013).
Public health expenditure	High costs associated with expensive and intensive treatments and escalation in resource utilisation are the direct monetary effects of AMR on health care (Prestinaci et al, 2015; Chokshi et al, 2019). In the UK, AMR costs the NHS £180 million every year (HoC, 2018). Worldwide, it is projected that AMR could cost from $300 billion to more than $1 trillion annually by 2050 (Chokshi et al, 2019; World Bank, 2017).
Economic impacts	An increase in AMR has severe global and national economic consequences as it causes increased mortality and morbidity, with knock-on effects of a decline in labour productivity, GDP, household income and tax revenues, and a rise in unemployment and inflation (Smith et al., 2005). Theoretical models have been used to estimate the economic impacts of AMR on the labour force in the future. These compare a baseline (absence of AMR) with the current trend in AMR as well as worse alternatives that might happen if appropriate measures are not taken. Results suggest that, if there is no change in the current pattern of AMR, in ten years, the world working age population would be lower by 2 to 92 million people compared to a world without AMR (Taylor et al, 2014). Global trade will be heavily affected by antimicrobial resistance if the continuous trends in AMR persist (Lekagul et al, 2019). The World Bank report demonstrates that global exports could decrease significantly by 2050 due to the effects of antimicrobial resistance on labour-intensive sectors (World Bank, 2017). A high AMR-impact scenario is projected to result in an almost 4% annual decrease in global GDP, or an annual shortfall of USD 3.4 trillion by 2030 (World Bank, 2017). Similarly, under the no action scenario, it is estimated that by 2050 more than ten million lives a year and a cumulative USD 100 trillion would be at risk (O'Neill, 2016). Multi-drug resistant tuberculosis alone for example could cost the global economy almost $17 trillion by 2050 (Economist Intelligence Unit, 2019). Thus, it can be concluded that the undesirable outcomes of AMR on the global economy are projected to be even more severe than the global financial recession due to its long-term impacts on the economy (World Bank, 2017).

Chronic	
Antibiotic-dependent industry impacts	In animals, AMR from intensive agricultural and livestock production systems leads to poor animal health which disrupts multiple critical supply chains such as food and trade of livestock (Woolhouse et al., 2015; George, 2019; Pokharel, Shrestha and Adhikari, 2020; Samtiya et al., 2022). The UK succeeded in reducing the use of antibiotics in animals by 40% between 2013 and 2017. However, due to an increase in global meat consumption, it is predicted that antimicrobial use in animals worldwide will increase by 67% between 2010 and 2030 (HMG, 2019). A decline in production and trade of livestock would result in elevated prices of protein due to the decrease in protein sources such as milk, egg, and meat (FAO; World Bank, 2017). Estimates have indicated that if the persistent trends in AMR do not slow down, there will be an 11% loss in livestock production by 2050, though this may be more severe in low-middle income countries (World Bank, 2017). In the environment, AMR as a result of contamination from pollution and waste contributes to reduction in water, soil, and crop quality (Grenni, Ancona and Barra Caracciolo, 2018), which directly affects food supply chains, and can also act as a source for further spreading to humans and animals (Samtiya et al., 2022; Larsson et al., 2023). Antifungal resistance also poses a significant threat to food security (Fisher et al, 2018). Regulation against the use of antimicrobial growth promoters (AGPs) in the livestock industry also poses a transition risk, as it potentially lowers productivity and increases production costs. There is evidence to suggest that this effect may be more pronounced in low-income countries (Laxminarayan et al. 2015).
Impact on food supplies and human wellbeing	Over-use of antimicrobials results in their increasing presence as microcontaminants in soil and water ecosystems, contributing to a reduction in water, soil, and crop quality, which directly affects food supply chains (Grenni, Ancona and Barra Caracciolo, 2018). Soil degradation from intensive agriculture has resulted in a decline in the nutritional value of food (Lal, 2009; a recent analysis of long-term trends in the mineral content of fruits and vegetables finds a reduction of up to 50% in some elements between 1940 and 2019 (Mayer et al, 2022). This has the potential to exacerbate widespread malnutrition-related disease, particularly affecting the elderly, with current costs to the healthcare system in England of £22.6 billion per year (Future Health, 2023). The decrease in quality of fresh food also contributes to child malnutrition, which has risen in the last 5 years and especially since the Covid-19 pandemic (Sustainable Development Goals, 2023), with negative impacts on child development and the resurgence of diseases such as rickets (Times Health Commission, 2023), often resulting in negative adult health outcomes (Early Intervention Foundation, 2020). Environmental factors also result in changes to the human gut microbiome which have potential to exacerbate the mental health crisis (Nurkolis et al, 2022, Liu et al, 2020); recent research estimates the impact of mental health on the UK economy in terms of labour availability and costs to health and education services of c. £118 billion per year (McDaid and Park, 2022).
Boost to pharmaceutical industry	Pandemic results in a boost to certain sectors such as the pharmaceutical industry (Esparcia and López, 2022). Pharmaceutical companies may however be under pressure to offer vaccines on a not-for-profit basis to avoid accusations of profiteering (de Haan and ten Kate, 2023). In terms of vaccines for AMR zoonotic diseases (Constanzo & Roviello, 2023), since Covid-19 pro-active vaccine development has been ramped up globally (Chatham House, 2022a). However, novel diseases may require new types of therapeutic and prophylactic medicines, and the loss of global biodiversity may also hinder options for development (Howes et al, 2020).

Acute	
Major livestock/ poultry disease	AMR in animals increases the risk of a major pandemic affecting livestock and poultry. In this scenario, an animal-borne pathogen (e.g, avian influenza or H1N1 swine flu) becomes widespread, meaning severe control measures are needed, and leading to widespread culling and collapse of the meat industry, and related industries, e.g. those that produce animal feed. There are historic cases of diseases that have been controlled to date (at substantial cost, e.g. foot and mouth in cattle, swine, sheep, goats and other cloven-hoofed ruminants; avian influenza; bovine TB) but there is also high potential for exotic diseases to gain a foothold in the UK; for example, brucellosis, Rift valley fever and Crimean-Congo haemorrhagic fever (PHE, 2023); there have also been some cases of bluetongue in England (Gov.uk, 2024). These risks are exacerbated by several factors, including climate change, which leads to intensive indoor-rearing to reduce GHG emissions and energy costs; an increase in global meat consumption (OECD-FAO, 2021), and global deforestation for cattle ranching (IPBES 2020) which increases the potential for human-wildlife interaction and the emergence of zoonotic disease.
Collapse of agricultural SMEs	Major livestock disease results in a shift in consumer preferences, leading to massively reduced sales, credit issues and the collapse of SME and agribusinesses. Precedents include Foot and Mouth disease in 2000, which cost the UK £25–30 billion through slaughter of cattle, loss of jobs and markets (FAO, 2004), and BSE in the 1990s, which cost the EU €92 billion long-term (FAO, 2009). Foot and Mouth also resulted in significant long-term health impacts in the most affected areas in the UK (Mort et al. 2005). The World Bank has estimated that zoonotic disease outbreaks in the first decade of the millennium cost worldwide more than $US200 billion due to loss of trade, tourism and tax revenues (Cartín-Rojas, 2012).
Global human pandemic	In the event of AMR leading to the emergence of a major human disease pandemic, a plausible worst case scenario is that mortality is more severe than Covid-19 (e.g. double the country level mortality, see JHU Coronavirus Resource Center, 2023). This is still conservative since avian influenza in humans, for example, can have a 60% fatality rate (Sah et al. 2023). Covid-19 led to a 9.7% decline in GDP in 2020, followed by recovery taking about 1.5 years. The Government's package of support for businesses, households and public services cost over £315 billion (UK Parliament, 2021). Government borrowing increased substantially from 80% of GDP before the pandemic to 95% of GDP afterwards. This puts the government in a poorer position to respond to future pandemics, especially if they are more severe than Covid-19.

Annex 5: NiGEM Model

Country model specification
NiGEM consists of individual country models for the major economies built around the national income identity, and contain the determinants of domestic demand, trade volumes, prices, current accounts and asset holdings. These models also incorporate a well-specified supply-side, which underpins the sustainable growth rate of each economy in the medium term. Country models are linked together through trade in goods and services, the influence of trade prices on domestic inflation, the impacts of exchange rates, and the patterns of asset holdings and associated income flows (represented using Armington matrices, currently using 2019 trade data). So, in NiGEM, a slowdown in a given country, associated with lower imports, would impact other countries through the effect of lower exports to that economy and associated shifts in asset prices. The overall impact would depend on both the underlying source of the shock and the policy responses (both in a country where the shock originates and other economies). NiGEM equations for differing countries combine a common theoretical structure across countries with estimation using country-level data so that the equations provide varying responses to a range of shocks. Constrained estimation techniques are employed, to ensure that all estimated parameters lie within theoretically plausible boundaries and that the model produces a coherent outlook for the future, which takes precedence over explaining the past. This leads to a common (estimated and calibrated) underlying structure across all economies with a relatively rigid long-run structure.

In the short-run, GDP is driven mainly by the demand side while in the long run, GDP is driven by the CES Cobb-Douglas production function. Deviations between supply and demand set in motion adjustment processes that bring the economy back to potential in the long run.

Country coverage
Individual country models are in place for almost all OECD countries. There are also separate models of Argentina, Brazil, Bulgaria, China, Egypt, Hong Kong, Indonesia, India, Malaysia, Romania, Russian Federation, South Africa, Singapore, Taiwan and Viet Nam. The rest of the world is modelled through regional blocks of Africa, Middle East, Latin America, Developing Europe, and East Asia, so that the model is fully global in scope. This ensures that there are no "black holes" in international transactions, as outflows from one country must be matched by inflows into other countries.

Policy environment
The scenario space in NiGEM, including policy regimes, expectation formation by consumers, firms, wage setters or financial markets, and other assumptions and judgements can be set by the model user. In standard simulations, financial markets are normally assumed to look forward and consumers are normally assumed to be myopic but react to changes in their (forward looking) financial wealth. Monetary policy is set according to rules, with default parameters calibrated for individual countries.

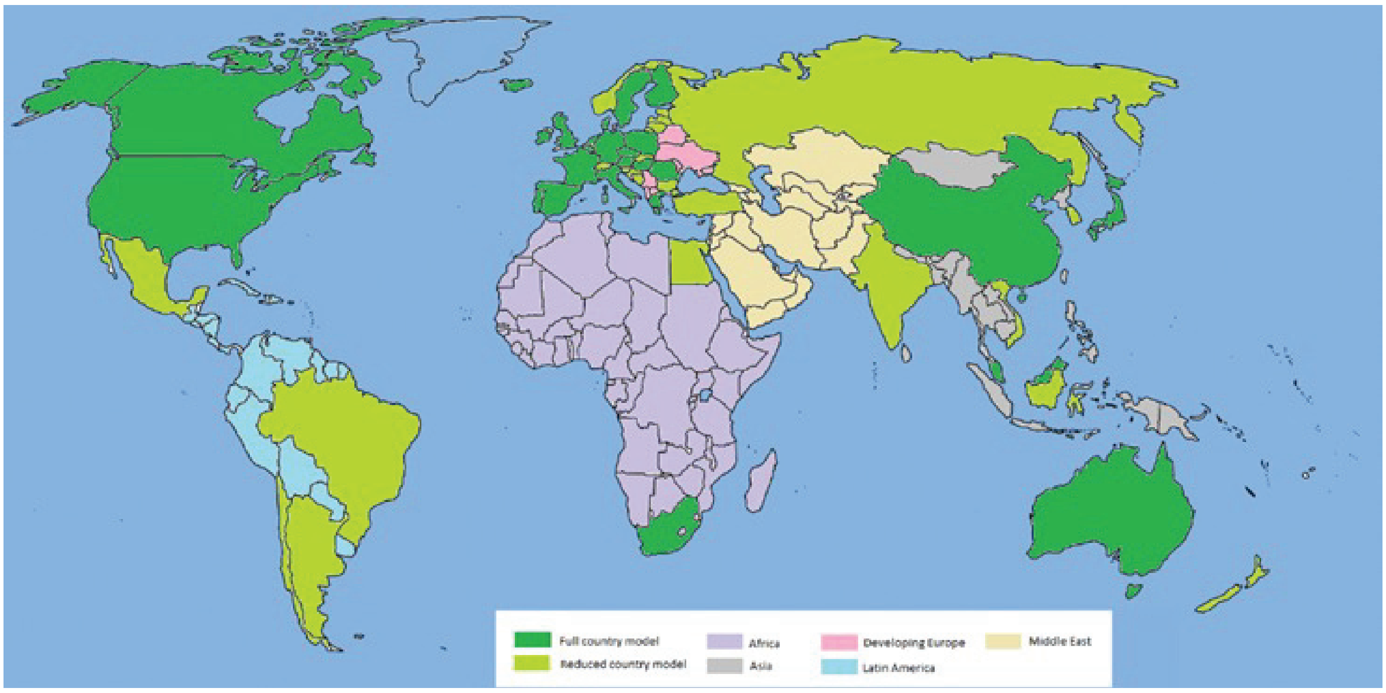


Figure 5.1: Map illustrating NiGEM coverage

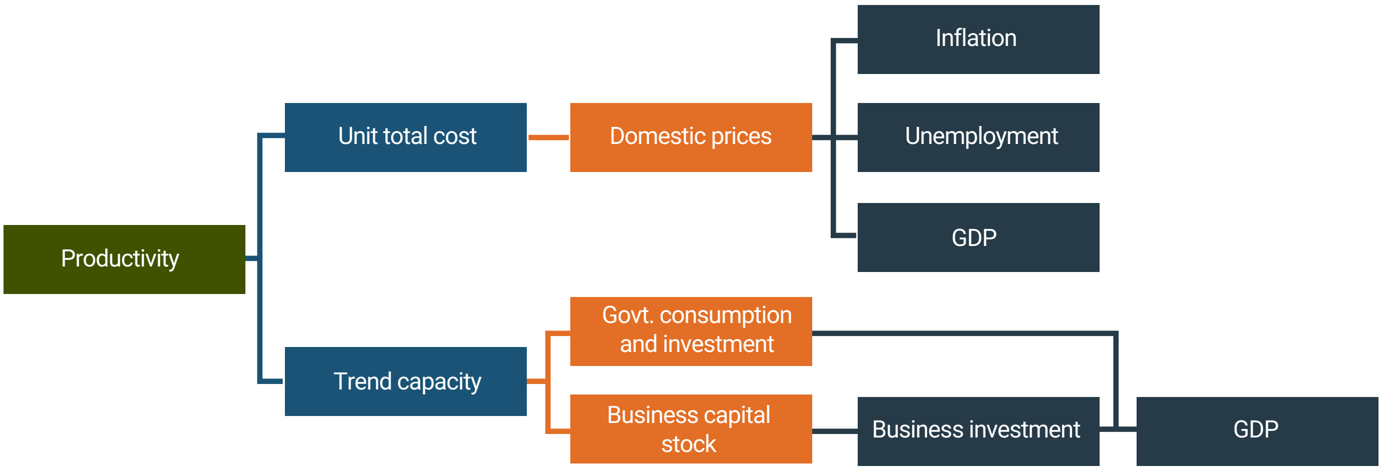
Modelling supply side shocks

In the long run, GDP is determined by the supply side and firms in NiGEM invest in capital, hire labour, and demand energy in order to supply the economy with goods and services. Aggregate supply, or capacity output (YCAP), is governed by an underlying production function driven by the factors of production: capital, labour and energy. The full country models are built around a constant-returns-to-scale (CES) relationship between capital (K) and labour (L), with labour-augmenting technical progress. This is embedded within a Cobb-Douglas relationship to allow the introduction of energy (M) as a factor input:

$$YCAP = \gamma\left\{\left[s(K)^{-\rho} + (1-s)(Le^{\lambda t})^{-\rho}\right]^{-\frac{1}{\rho}}\right\}^{\alpha} M^{1-\alpha}$$

YCAP: Potential output
K: Total capital stock
L: Trend hours worked (ETRND)
λt: Index of labour-augmenting technical progress (TECHL)
M: Energy input, defined as OIVOL*Y, where Y is GDP and OIVOL is the volume of energy input as a share of GDP, which can be interpreted as the energy intensity of production
α = is a constant term that sets the trend energy share of input costs for production

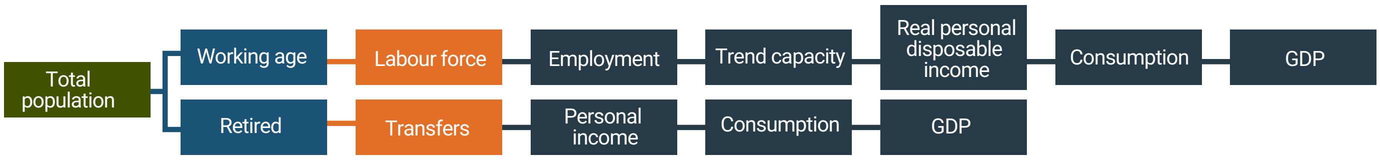
Two direct supply shocks used are the impact on labour augmenting technology and a direct shock to the trend capacity. The propagation of these shocks within NiGEM is shown below.



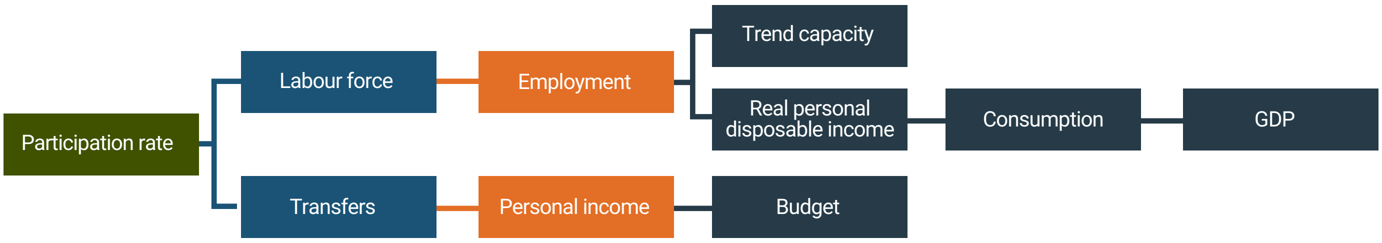
A fall in productivity (labour augmenting technical progress) reduces trend capacity. This or a direct shock to trend capacity is a supply side shock, with the demand side of the economy adjusting towards new lower level of long-term output. If, initially, demand is higher than supply, a positive output gap will develop inducing a rise in prices. Interest rates will increase to counteract this price increase.

Population shocks

Population effects act on both supply and demand. A direct population shock can use either total population where the entire economy is impacted by the shock or a more targeted approach which uses differential impacts on total population and the population of working age.

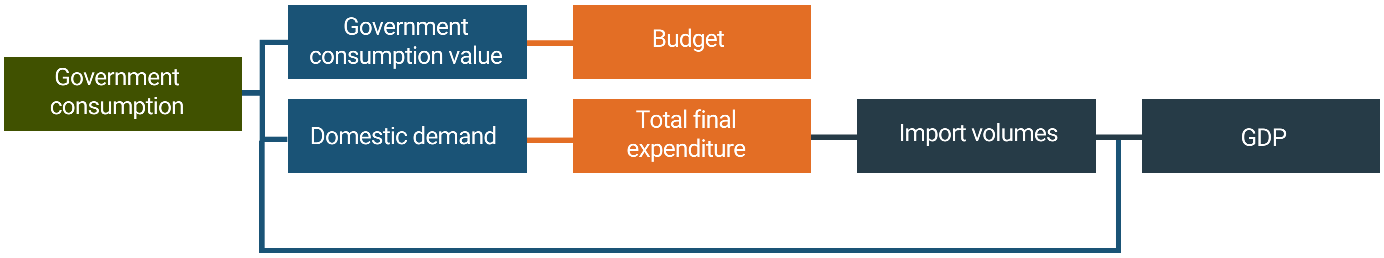


Alternatively, the participation rate can be used to reflect a change in workforce efficiency.



If participation is reduced, labour availability (a factor input in production function governing potential output) will fall so trend capacity in the economy will be permanently lower. A lower productivity and reduced availability of labour force will cause wages to rise initially, leading to a higher production cost resulting in a price increase and triggering a counteracting monetary policy response.

Government shocks
Both government consumption and government expenditure (govt. consumption value) are implemented within the scenarios.

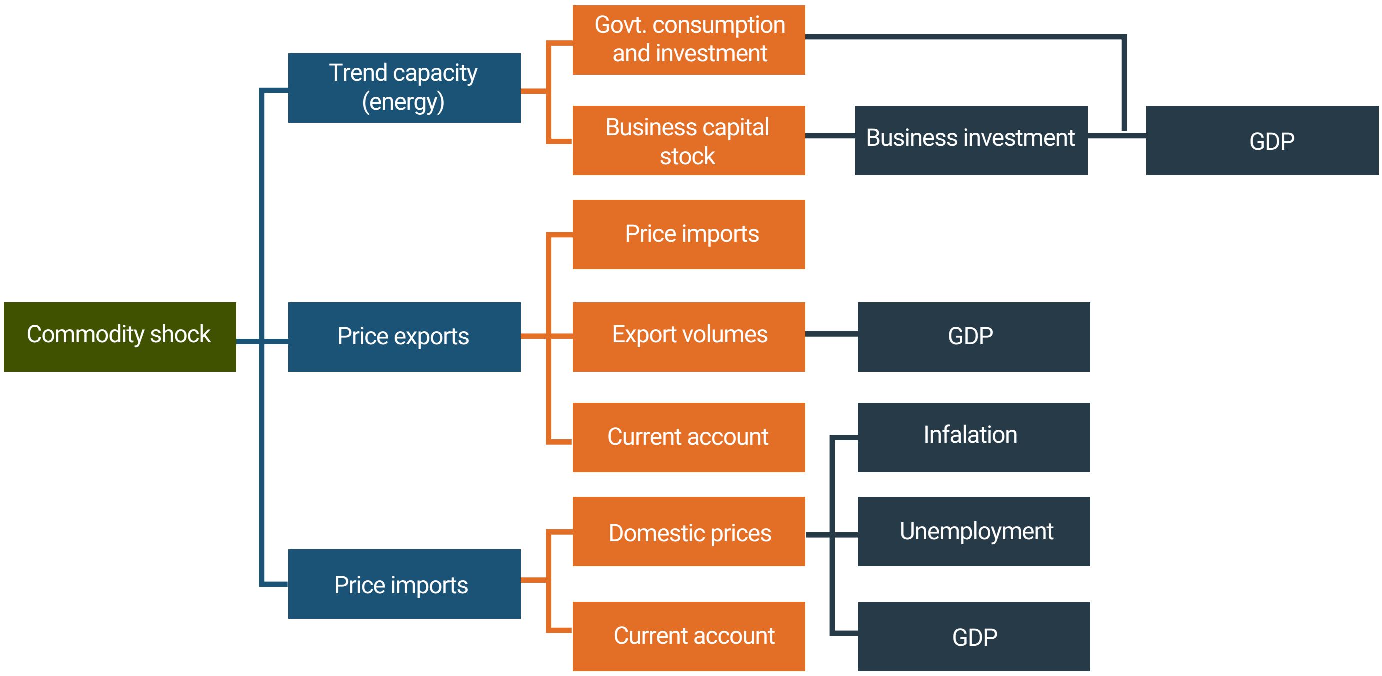


A rise in government spending worsens the government's fiscal position and leads to increase in debt to GDP ratio, while having a temporary impact on GDP.

Commodity and price shocks
Three different prices shocks are considered:

1. Energy price shock (commodity, energy)
2. Price of exports
3. Price of imports/exports of commodities

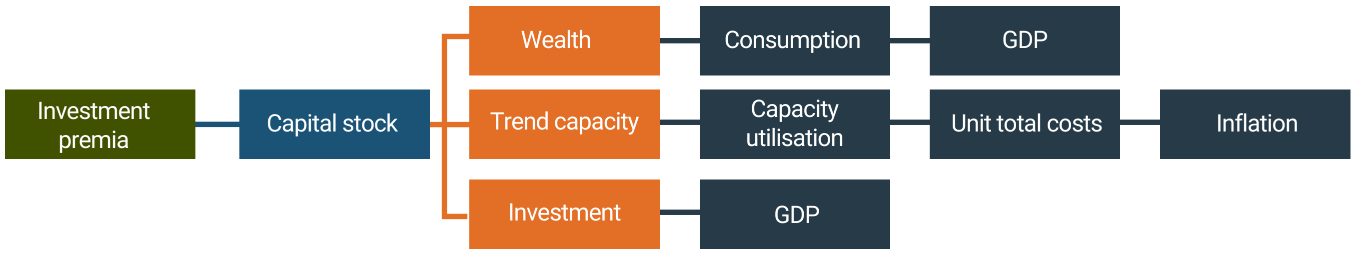
Note: Import and export price of commodities are not directly linked so both were shocked to ensure consistency of the price change.



A price increase depresses household consumption via reduced real disposable income. With inflation being above the target, monetary policy responds with interest rate increase. The resulting increase in user cost of capital leads to a lower level of capital in the economy and reduction in investment.

Risk shocks (premia)

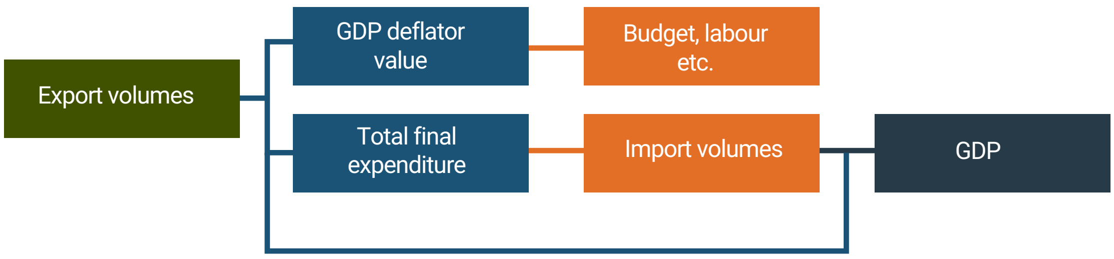
Capital stock damage throughout the chronic and acute scenarios is modelled via increase in risk premia. Its impact on the economy mimics the impact of a reduction of available capital with a resulting negative impact on both supply and demand sides of the economy.



A permanent increase in risk premia has a long lasting permanently negative impact on the economy. However, there will be some mitigating impacts from falling prices and accommodative stance of monetary policy, with lower interest rates somewhat counteracting the initial damage from the shock.

Direct trade

A further worsening of net trade position can be modelled using a direct shock to export volumes, impacting both import volumes and the GDP deflator leading to first and second round impacts on GDP.



Annex 6: Specification of Quantitative Scenarios for NiGEM

Domestic scenario

Scenario	NiGEM implementation
Acute	
1. Increased in prices of electricity , proxied within the model as an increase in public expenditure, which increases prices. Water supply disruption and pollution impacts	This is an increase in public expenditure accompanied by the price shock. The rise in government spending worsens the government's fiscal position leading to increase in debt to GDP ratio, while having a temporary impact on GDP. The Price increase depresses household consumption via reduced real disposable income. With inflation being above the target, a monetary policy responds increasing the interest rate resulting in an increase in user cost of capital which leads to a lower level of capital in the economy and reduction in investment.
2. Reduced productivity of agriculture. Damage to soil health and subsequent increase in food prices.	Modelled as a supply side shock with a reduction in trend capacity output. The demand side of the economy adjusts towards a new lower level of long-term output. With demand initially higher than supply, a positive output gap develops, and prices rise. Interest rates increase to counteract the price increase.
3. Increase in public expenditure. Health expenditure impacts associated with air pollution and reduced biodiversity-rich green spaces.	The rise in government spending worsens the government's fiscal position and leads to increase in debt to GDP ratio, while having a temporary impact on GDP.
4. Reduction in labour availability Impacts of air pollution and associated loss of biodiversity-rich greenspace in urban areas on labour productivity.	Modelled as a fall in productivity (labour augmenting technical progress) and reduction in available labour force through the participation rate. Given that labour is a factor input in production function governing potential output, trend capacity in the economy will be permanently lower. Lower productivity and reduced availability of labour force will cause wages to rise initially. Higher production cost (including the wage rise) results in a price increase, triggering a counteracting monetary policy response.
Acute #1	
1. Reduction in Labour productivity. Heat impact on major cities (health impacts) with reduced overall productivity and labour productivity	Temporary fall in productivity (labour augmenting technical progress) impacting trend capacity.
2. Reduced productivity of agriculture Drought and heatwaves reduce crop yields in UK and Northern Europe.	Direct, temporary supply side shock (trend capacity) with the size modified by the GVA proportion agriculture exerts in the economy.
3. Increase in public expenditure. Drought and heatwaves reduce water availability in the UK.	This is a direct price shock coupled with increased public expenditure.

Acute #2	
1. Capital stock damage – due to a major wildfire outbreak.	Modelled via increase in risk premia as its impact on the economy mimics impact of a reduction of available capital. This results in a negative impact on both supply and demand sides of the economy.
2. Labour availability – caused by acute air pollution impact from major wildfires and disruption of transport.	Direct, temporary supply side shock (trend capacity) with the size modified by the GVA proportion agriculture exerts in the economy.

International (supply chain) scenario

Scenario	NiGEM implementation
Chronic shocks	
1. Growing fiscal issues and financial sector vulnerabilities globally	Modelled via increase in investment and term structure risk premia. Investment premia aims to capture rise in risk premia and credit rationing in the business sector above the risk free rate. While term structure risk premia causes the market price of government bonds to fall.
2. Food insecurity, rising due to disruption of cereal and fruit/veg production across the world from pollinator loss, fertilizer price rises and soil health degradation in concert with climate impacts	Impact on commodity trade via increase in non-commodity trade prices globally.
3. Reduction in biofuel production in response to food crisis	Causes increase in world price of oil, which leads to rise in production costs affecting both supply and demand sides of the economy.
Acute #1	
1. Multiple breadbasket failure - Up to 20% loss in global cereals outputs, resulting in major food insecurity issues	Global prices of commodities rise. Modelled via increase in both import and export commodity prices.
2. Geopolitical instability – conflict and trade-wars	Manifests itself via higher commodity prices, specifically world price of oil, leading to worldwide price increase and lower global output.
Acute #2	
1. Geopolitical instability – conflict and trade-wars	Public expenditure increases. Economic and political uncertainty leads to rise in investment and term structure risk premia.

Health (Amr-Pandemic) scenario

Scenario	NiGEM implementation
Chronic shocks	
1. Anti-Microbial Resistance (AMR) leads to global increase in diseases, with longer and higher impact in fatalities and morbidity due to lack of vaccine.	Modelled via reduction in total as well as working age population, reflecting the loss of lives and reduction in the labour force. This affects the productive capacity of the economy, impacting both long-term and short-term output. Public expenditure increases, as the government is compelled to bolster its health expenses to combat the disease. Given the global nature of the shock and its probable impact on productive capacity worldwide, a further reduction in world labour augmenting productivity is included, depressing the supply side of the world economy. Reduction in countries' productive capacity and the demand reduces trade, which is modelled via fall in exports shares in advanced economies.
Acute #1 and #2	
1. Major livestock/poultry disease outbreaks	Modelled via reduction of productivity and a fall in trade shares, in the UK.
Acute #3	
1. AMR leads to pandemic with economic shutdowns similar in magnitude to COVID-19 global impact	The shutdowns in the economies are modelled via a combination of several shocks: reduction in productivity, increase in non-commodities prices globally, and a reduction in household consumption. All the above shocks are calibrated based on historical data from the COVID-19 outbreak.

Annex 7: Systemic Risk Component Analysis

This annex provides a summary of 'systemic risk dimensions' which are indirect pathways of risk transmission by which nature degradation can impact the economy and financial stability. These aspects are not currently included in NiGEM modelling and may make the estimates to GDP impact therein more conservative. This annex includes a 'long-list' of several systemic risk dimensions for each scenario (Table A8.1). We have then selected one broad type of systemic risk dimension per scenario to unpack with a more detailed evidence review. These specific examples were chosen because they represent potentially important (financially material) risks that are relatively neglected in terms of quantitative modelling. They are:

Domestic scenario – biodiversity loss impacts on both mental health and civil unrest
International (supply chain) scenario – famine and civil unrest from food supply disruption
Health (AMR-pandemic) scenario – major livestock/poultry disease leading to collapse of livestock companies

Biodiversity loss impacts on both mental health and civil unrest (domestic scenario)

This section outlines in more detail two systemic risk dimensions associated with biodiversity loss. The risks occur through two pathways: i) mental health and credit risks, both arising as consequence of biodiversity loss, ii) civil unrest, protest and operational risks

Pathway#1: Continued biodiversity loss exacerbates the mental health crisis, not only reducing labour productivity but driving micro-economic impacts through increasing mortgage defaults (credit risk).

Likelihood:
Biodiversity (whether perceived or actual) has been demonstrated to improve mental wellbeing, by reducing stress, improving cognitive function, increasing social cohesion and fostering imagination and creativity, particularly in children (Cianconi et al. 2023). Biodiversity can also play an important role in the treatment of mental health disorders such as anxiety; in the same way, biodiversity loss has been shown to have a negative impact on mental health, potentially resulting in so-called 'psychoterratic syndromes', characterised by feelings of anxiety, helplessness, guilt and solastalgia, which are now more prevalent due to increased awareness of environmental issues (Cianconi et al. 2023).

Impact:
Recent research estimates the impact of mental health on the UK economy in terms of labour availability and costs to health and education services of c. £118 billion per year (McDaid and Park, 2022). Stress, depression or anxiety accounted for the majority (17.1 million) of working days lost (WDL) due to ill health in 2022/23, and the current total rate of WDL is higher than the 2018/19 pre-pandemic level (HSE). A recent report estimated that absence from work due to mental illness resulted in an average £2200 fall in individual income and had a negative effect on future employment prospects (The Guardian, 2023). Income shocks and unemployment are amongst the main determinants of mortgage defaults and repossessions (Linn and Lyons, 2020). These have both increased in recent years (although in the context of a long-term downward trend); the number of repossessions has been rising since 2021, and the number of mortgages in arrears by 2.5% or more has been rising since late 2022 (HoC, 2023b). However, evidence directly linking such changes to mental health exacerbated by biodiversity loss is currently lacking.

Pathway# 2: Continued biodiversity loss drives civil unrest and disruption of finance institution processes through blocking access of workers to banks and increasingly well-organised cyber disruption (operational risk).

Likelihood:
In recent years, environmental activism in the UK has increased. Groups such as Extinction Rebellion, for whom biodiversity loss is a core issue, have organised mass protests leading to thousands of arrests (London Assembly, 2022a). Extinction Rebellion specifically target the finance sector, engaging in activities such as mass protests, roadblocks and damage to property at banks and financial institutions, leading to operational risks (Extinction Rebellion). Opinion polls indicate that 76% of adults in Great Britain worry about climate change and the environment (ONS, 2021c), and 66% support direct action on environmental issues (Omnisis, 2022). Mass involvement in direct action is still however relatively unlikely; in 2020, less than 10% of poll respondents had taken part in some form of environmental campaigning (HoC, 2020), and some polls suggest that public opinion of groups such as Extinction Rebellion and Just Stop Oil is still largely negative (YouGov.uk, 2021; YouGov.uk, 2023).

There is potential for environmental protest to increasingly adopt cyber-attacks to cause disruption. Weekly cyber-attacks from all causes increased worldwide by 7% in the first quarter of 2023, with organisations in the education and research sector most frequently targeted (Infosecurity, 2023). The frequency and impact of cyber-attacks on digital infrastructure is increased by advancements in AI (Shabsigh & Boukheruaa, 2023). Implementation of sustainable technologies also has the potential to increase risk of cyber-attacks (International Airport Review, 2023). However, as yet cyber-attacks have not been a notable feature of climate activism; an exception is the leaking of personal information of delegates to COP21 by the hacker group Anonymous in 2015 (The Guardian, 2015).

Impact:
Protests organised by Extinction Rebellion leading to high numbers of arrests resulted in costs to the Metropolitan Police of £79.1 million between April 2019 and April 2022 (London Assembly, 2022b). However, these costs are likely to have reduced since January 2023, when Extinction Rebellion announced their decision 'to temporarily shift away from public disruption as a primary tactic' (BBC, 2023). The more general economic costs associated with environmental activism are harder to ascertain. In 2021 a contemporary news source stated that Extinction Rebellion roadblocks in September of that year caused disruption to transport infrastructure resulting in estimated economic losses of £883,962, according to a report prepared by barristers acting on behalf of National Highways (Evening Standard, 2021). In extreme cases, environmental activism has also been shown to have a direct impact on a company's market value (primarily via reputational damage) leading to its ultimate failure (Lewis et al. 2017).

A recent government report categorises cybercrime costs in three ways: 1) anticipation (eg. implementation of security measures such as anti-virus software); 2) consequence (eg. fraud, loss of intellectual property, disruption, damage to reputation), and 3) response (costs of law enforcement and judicial process, implementation of training, PR activities) (Home Office, 2018). Global estimates of the cost of cybercrime vary widely (Wright and Kumar, 2023). Measuring the overall cost of cybercrime to the UK economy has also proved problematic; a literature review conducted as part of the same report found 'no estimate of the overall cost of cyber crime, that could be interpreted with a high level of confidence' (Home Office, 2018). A recent UK government survey found that 1% of businesses and 8% of charities had been the victim of cyber crime in the last year, with an average (mean) annual cost for businesses of approximately £15,300 per victim (Gov.uk, 2023a).

Famine and civil unrest from food supply disruption (International supply chain scenario)

In this section we outline a systemic risk dimensions of global food insecurity, resulting in sudden import shortages, causing famine, rising food prices and major civil unrest over several months, reducing labour productivity and disrupting political processes causing strategic and liquidity risks for government and financial institutions.

Likelihood:

Global food insecurity has risen since the Covid-19 pandemic; a recent report by the UN states that the proportion of the world population facing chronic hunger in 2022 was about 9.2 per cent, compared with 7.9 per cent in 2019 (FAO, 2023). The UN states that the global food system relies on a series of dependency relationships which are vulnerable to crises such as conflict or pandemic; these include dependencies on food exports, food imports, fertilizers or on a single food group such as wheat (UN, 2022), all of which are vulnerable to the disruption of global supply chains. The same report states that conflict, rather than lack of supply, is the primary driver of global food insecurity; the invasion of Ukraine by Russia resulted in wheat price increases of almost 70% (UN, 2022). Global conflict is increasing; as of January 2024 the ACLED Conflict Index recorded an increase of over 40% compared to 2020, with the situation worsening in key sites of conflict such as Palestine, Haiti and Sudan (ACLED, 2024). Social unrest (ie. riots and protests) is also increasing globally, although this trend was interrupted by the Covid-19 pandemic lockdowns (IMF, 2021).

Impact:

At a national level, food price volatility is a primary cause of food riots and civil unrest, which have an adverse effect on economic activity, reducing GDP by an average 0.2 percent, rising to 1% for a significant unrest 'event' (Hadzi-Vaskov et al, 2023). Civil unrest is also shown to have an adverse effect on stock market performance, causing an average 1.4 percentage point drop in returns over a two-week period for countries which experienced a significant unrest event; however in countries with stronger and more democratic institutions, this effect was significantly reduced (Barrett et al. 2021). The effects of food price volatility can be mitigated via government financial assistance schemes, as were instituted during the Covid-19 pandemic, but these are costly (Fontan-Sers and Mazhar Mughal, 2023).

Global food insecurity is a contributing factor to the cost of living crisis in the UK, which has resulted in recent industrial action (Milner, 2022) and a significant number of working days lost: between April 2022 and May 2023, 3.9 million working days were lost to strikes, more than at any point since 1989 (Resolution Foundation, 2023). Industries that were affected by strikes showed evidence of shrinking output at the end of 2022, and GDP is estimated to have fallen by 0.5% in December of that year (ONS, 2023c). However, the full impact of strikes is difficult to measure as their effects can be wide-ranging; for example over half (59%) of parents surveyed in December 2022 said that their ability to work would be affected because of school closures due to strikes (ONS, 2023c).

Major livestock/poultry disease leading to collapse of livestock companies (Health AMR-pandemic scenario)

In this section, we investigate the systemic risk dimension of impacts from major livestock/poultry disease leading to collapse of livestock companies. This risk could include culling of livestock and food scares leading to consumer aversion.

Likelihood:

FAIRR's Emerging Disease Risk Ranking 2022 examined the role of intensive animal agriculture in the spread of livestock disease by evaluating companies against six risk indicators: (i) deforestation and biodiversity loss; (ii) antibiotics; (iii) waste and pollution; (iv) working conditions; (v) food safety; and (vi) animal welfare (FAIRR, 2023). They found that, of the five major protein-producing sectors (poultry and eggs; pork; dairy; beef and aquaculture), all with the exception of aquaculture were rated as high risk between 2019-2021, with the beef sector having been upgraded to medium risk in 2022 (FAIRR, 2023, fig. 8). In 2022 a report by the Public Accounts Committee found that the Animal and Plant Health Agency (APHA) in Weybridge (the UK's main animal disease facility) had been left to deteriorate to an 'alarming extent' leaving the country vulnerable to major outbreaks of livestock disease (HoC, 2022). The outbreak of avian influenza in the UK and Europe in 2021-22 has been classified as the worst ever in the region, and a recent report by the Centre for Innovation Excellence in Livestock states that 'Both the frequency and severity of HPAI outbreaks have increased, justifying planning for living with an elevated avian influenza risk' (CIEL, 2023). Following the ban on feeding mammalian protein to livestock in 1996, BSE is no longer thought to pose a significant threat to the UK, with expectations of only occasional cases occurring up to the year 2026 (Alarcon et al. 2023).

Impact:
Barratt et al. 2019 distinguish between direct costs of animal disease ('animal mortality, morbidity, and associated response costs') and indirect costs, which they define as 'the economic losses incurred in markets after disease freedom is declared'. In 2010, the World Bank estimated the emergence of BSE, SARS, avian flu and swine flu to have cost $20 billion in direct economic losses over the previous decade and more than $200 billion in indirect losses (World Bank, 2010). The most prominent direct economic impact of livestock disease is a decline in production and consequent loss of farm income, which will vary according to the extent to which the farm economy is diversified (FAO, 2004). Precise economic effects may be difficult to measure due to the possibility of 'hidden' long-term effects, such as delays in reproduction leading to a reduced population (FAO, 2004). Wider market impacts may include shifts in consumer preference, or trade bans and restrictions in response to an outbreak (Kappes et al. 2023). In developing countries, food security and nutrition may also be negatively affected (Kappes et al. 2023).

Following the discovery of the link between BSE and vCJD, UK consumption of beef fell immediately by around 40%, precipitating a fall of 25% in beef prices (Alarcon et al. 2023). As a consequence by 1999 only 412 of the 1000 abattoirs that had existed in 1986 remained in operation - a reduction of 59% (Lloyd et al. 2006). Bans on beef exports as a result of BSE have been estimated to have cost the US $6.1 billion between 2004 and 2013, and Canada $1.7 billion (Peterson et al. 2017). In the US, it is estimated that avian influenza has resulted in approximately 40 million animals being culled and economic costs of between US$2.5 and US$3 billion (FAIRR, 2023). Mass culls of poultry in the UK following the 2021-22 AI outbreak caused egg shortages and a spike in egg prices, and a rise in price of 24.4% for outdoor-bred turkeys during Christmas 2022 (FAIRR, 2023). An Irish poultry company reported a fall in pre-tax profits of 90% from £17.8 to £1.7 million in 2020 as a result of AI, inflation and animal feed price rises due to the war in Ukraine (FAIRR, 2023).

Annex 8: Nature 'stress test' methodology

We consider a set of scenarios that includes a "Baseline scenario" (abbreviated as B), in which biodiversity loss impacts do not occur, and scenarios of nature and biodiversity loss i.e., a "Domestic Scenario" (D) and International Scenario ("I"):

- The baseline scenario does not consider biodiversity loss and environmental degradation. This scenario corresponds to a situation in which investors neglect biodiversity risk. Indeed, the relation between biodiversity risk and finance has been little documented and analysed so far. Thus, the rationale to assume that investors have not formed expectations about biodiversity risk (because complex, not happened so far).
- In the domestic scenario, there is a growing chronic impact and an acute shock on a selection of ecosystem services in the UK, which impact directly on the UK economic activities (indirect impacts from international trade via the portfolio are not considered).
- In the international scenario, only the indirect effects on UK activities are considered, resulting from shocks on chronic and acute shocks on ecosystem services outside the UK, through supply chains.

We denote the generic scenario as C, while the nature and biodiversity loss scenarios are denoted as P. A key variable is the cumulative future value of output of firm j from period t = 0 up to period T compounded at interest rate r, denoted as $\overline{X}^C_{j\,T}$ and expressed as

$$\overline{X}^C_{j\,T} := \sum_{t=0}^{T} (1+r)^{T-1} X^C_{j,t} \tag{1}$$

where $X_{j,t}^C$ denotes the output at time t. Further, it is of interest the quantity

$$\Delta \bar{X}^P_T = \frac{\bar{X}^P_T - \bar{X}^B_T}{\bar{X}^B_T} \tag{2}$$

In this application we assume that the output over time of the firm is proportional to the output of the sector in which it operates.

We denote with the default probability in a generic scenario P of a firm operating in a single sector. Such probability depends on a few parameters as follows

$$\mathrm{PD}^P_j = f(E_0, r, d, \mathbf{X}^P, \mathbf{X}^B, \lambda, \delta, \tau). \tag{3}$$

In Battiston et al. 2022, it is shown that is a non-linear but non-decreasing function of $\Delta \bar{X}^P_{j\,T}$

For simplicity, we take the linear approximation as follows

$$\mathrm{PD}^P_j \approx \mathrm{PD}^B_j + \chi\, \Delta \bar{X}^P_{j\,T}, \tag{4}$$

where **χ** is an elasticity coefficient, and PD^B is the default probability in the baseline scenario.

In line with standard accounting procedure in the banking sector, the expected value of a loan can be written as

$$\mathcal{B}^C_j = (1 + r^C_0)^{-T} \left[(1 - \mathrm{PD}^C_j) + \mathrm{PD}^C_j R^C \right] \tag{5}$$

Finally, the adjustment in financial value for a single loan is

$$\Delta \mathcal{B}^P_j = \frac{\mathcal{B}^P_j - \mathcal{B}^B_j}{\mathcal{B}^B_j} \tag{6}$$

As a stress test, we combine the domestic and international scenarios given that they both explore independent aspects of risk.

We consider the portfolio of loans and advances of the seven largest UK banks, i.e. Barclays, HSBC, Lloyds, Standard Chartered, NatWest, Santander UK, and Nationwide. The total value of the analysed portfolios is close to 717 GBP billion, so a subset of the full UK financial system. The largest allocation of loans of the seven banks is to financial activities, followed by manufacturing[21].

Now we move to the level of a loan portfolio held by a bank. Note that represents the unitary value of the loan B_j^B, while we denote with the number of units of bond ***j*** held in the portfolio.

[21] We exclude the financial holdings from this analysis, given that we have no information about the real economy sectors that these assets are financing and therefore, no way to assess the nature-related financial risks associated with them. In this study, we effectively assume that those assets face a risk that mirrors that of the rest of the portfolio. Further work is required with financial institutions to clarify this assumption and refine the analysis.

The portfolio value, is the sum of the values of the holdings in each loan *j*,

$$\mathcal{B}^B = \sum_j \tilde{w}_j \, \mathcal{B}_j^B \tag{7}$$

We denote the adjustment in the portfolio value when going from scenario *B* to *P* as $\Delta\mathcal{B}^P$,

It is useful to express $\Delta\mathcal{B}^P$ as follows

$$\Delta\mathcal{B}^P = \frac{\mathcal{B}^P - \mathcal{B}^B}{\mathcal{B}^B} = \frac{\sum_j \tilde{w}_j \, (\mathcal{B}_j^P - \mathcal{B}_j^B)}{\mathcal{B}^B} = \\ = \sum_j \frac{\tilde{w}_j \mathcal{B}_j^B}{\mathcal{B}^B} \frac{\mathcal{B}_j^P - \mathcal{B}_j^B}{\mathcal{B}_j^B} = \sum_j w_j \, \Delta\mathcal{B}_j^P , \tag{8}$$

where w_j represents the weight of the holding in loan *j*, relative to the whole loan portfolio value, in scenario *B*.

The nature and biodiversity loss scenarios *D* and I provide impacts on output (GVA) of certain sectors of the real economy. Finance is not included.

Here we consider loans to representative firms of each sector. We then apply Eq. 8 with j running across the sectors of the economy, w_j being the relative exposure of the bank to the sector *j*, and $\Delta\mathcal{B}_j^P$ being the adjustment in the value of the loan to the representative firm of sector *j*.

Results for the portfolios excluded finance and services are shown in the main text. Results for the whole portfolios are given below. Note caution at interpreting these results given the lack of information about the sectoral exposures of the financial portfolios.

	Bank 1	Bank 2	Bank 3	Bank 4	Bank 5	Bank 6
Domestic	**0.17%**	**0.40%**	**0.70%**	**0.17%**	**0.69%**	**0.24%**
Dom + International	**0.442%**	**0.724%**	**1.096%**	**1.090%**	**0.440%**	**0.526%**

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