Green Finance Institute

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

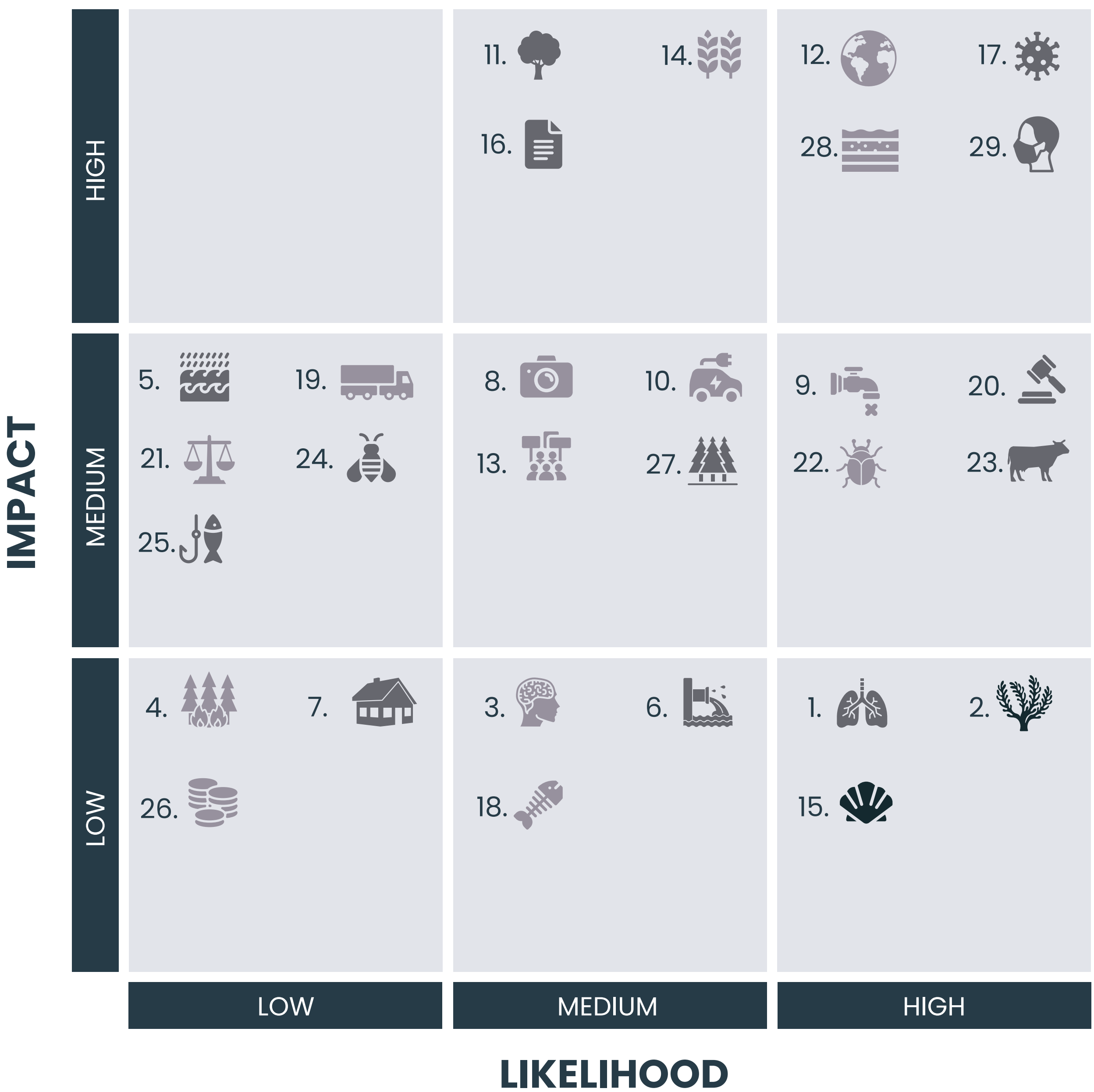
SUPPLEMENTARY MATERIALS 1

April 2024

UK Nature-Related Risk Inventory evidence statements

This Supplementary Material provides the evidence statements for the UK Nature-Related Risk Inventory (NRRI) developed as part of this project. Please see main report Chapter 1 for the methodology used to score the likelihood and impact of each risk, and for further analysis on the associations between risks and how they can be developed into compounding risk scenarios.

Each risk statement in this Supplementary Material provides evidence for the likelihood and impact of each nature-related risk to the UK. Also detailed are compounding threats, which are other related risks deemed to have medium (normal font) or high (bold font) association with the focal risk.



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 S1, 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 in main report). 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 scenarios and evidence statements

Mainly Domestic risks
Air pollution from wildfires
Algal blooms in water ecosystems
Biodiversity access and mental health
Direct damage from wildfire
Flooding due to deforestation and soil damage
Freshwater pollution
Housing asset risks due to policy and legal changes
Risks to tourism from nature damage
Water shortages impact energy and agriculture

Mainly International risks
Critical resource supply chain disruption
Deforestation and ecosystem tipping points
Global food security repercussions
Global food supply chain interruption from biodiversity-climate policy misalignment
Multiple breadbasket failure
Ocean acidification

Both Domestic and International risks
Acceleration of strict net zero policies
Anti-microbial resistance
Aquaculture major pest or pathogen outbreak
Business impacts due to UK-only biodiversity policies
Corporate litigation cases
Government litigation casesGrain crops pest / pathogen outbreak
Livestock disease
Loss of pollination service
North Sea fishery collapse
Reputational risk, stranded assets and fund withdrawal
Sitka spruce pest outbreak
Soil health decline
Zoonotic disease

Mainly Domestic risks

Risk title: 1) Air pollution from wildfires
One sentence risk description: Air pollution from wildfires in an urban setting.
Risk type: Physical
Risk source and timeframe: Either transboundary or domestic, both acute and chronic
Plausible worst case scenario: Large-scale and/or multiple wildfires in the UK occur as a consequence of land use decisions (e.g. monoculture forestry, dry soils as a consequence of water mismanagement such as over-abstraction) and through interactions with climate change (e.g. intense heatwaves and drought). Wildfires may also occur concurrently in nearby countries. They lead to poor air quality, adding to industrial/transport air pollution (also potentially exacerbated by changes to tree cover and reduced urban vegetation - e.g. reduced trees that shield/reduce air pollution and increase in ozone from precursor volatiles released by bioenergy crops). Poor air quality impacts the health of local residents, which leads to an increase in likelihood of premature deaths and incidence of diseases; there is evidence that air pollution has led to high non-communicable chronic disease burdens through respiratory disease, cancer, allergies, birth defects and impaired cognitive development, particularly in an urban context. In extreme cases wildfires can cause an increase in air pollution to the point of excess death (see Shaposhnikov et al, 2010, although the likelihood of wildfires of that extent is much lower in the UK). Consequences include a reduction or permanent loss in labour productivity and pressure on the healthcare sector. Critical infrastructure and supply chains may also be disrupted due to workforce absences as well as smoke disrupting transport in the acute phases.

Rationale for likelihood:
Global extreme fires are expected to increase by up to 14%, 30% and 50% in 2030, 2050 and 2100 (UNEP 2022). 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). 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). Wildfires in other countries could also exacerbate air pollution, with 20% of all particulate matter pollution from all sources currently coming from other countries (Defra, 2023g).

Rationale for impact: Air pollution is the "single greatest environmental threat to health in the UK" (EA, 2023c), causing between 29,000 to 43,000 excess deaths per year (Defra, 2023g). 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). Three million working days are lost (WDL) in the UK due to air pollution (CBI, 2020), approximately 10% of the ill health-related total (HSE). 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, and surpassing the lower estimate of projected deaths by 2060 (6-9 million, (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,2023). Wildfires increase particulate matter impacting mortality and morbidity from cardiovascular and respiratory diseases, as well as potential carcinogenic impacts (PHE, 2018b). Economic valuation from Los Angeles, USA, of the health effects of wildfire smoke exposure, including defensive actions taken as well as disutility, were $84 per exposed person per day (Richardson et al., 2012), which sums to substantial total costs when large urban populations are exposed for extended periods. In terms of acute exposures, the UK Saddleworth Moor fire in 2018 led to PM2.5 concentrations increasing by more than 300% in Oldham and Manchester and up to 50% in areas up to 80 km away such as Liverpool and Wigan, equating to 4.5 million people being exposed to PM2.5 above the WHO 24-hour guideline of 25 μg m^{-3} on at least one day. One study calculates the short-term health impact over a 7-day period of 28 (95% CI: 14.1–42.1) deaths brought forward, with a mean daily excess mortality of 3.5 deaths per day (95% CI: 1.8–5.3) (Graham et al. 2020). The impact of mortality due to PM2.5 from the fires on the economy was c. £21.1M.

Compounding threats: Algal blooms, Biodiversity; **Deforestation; Wildfires;** Grain crop pests, Risks to tourism; **Sitka spruce pest; Soil health decline; Acceleration of strict net zero and nature protection policy.** Other factors: Heat waves both exacerbate fire risk and air pollution. Contaminants become trapped during stagnant heat wave conditions causing high concentrations as urban emissions accumulate. Note that in Australia, loss of small digging mammals has exacerbated the severity of wildfires due to changed litter (i.e. fuel) dynamics (Watson, 2016). In Mediterranean systems, there is correlative evidence that agroforestry systems (with a mix of biodiversity, woody and herb species) have fewer fire-related incidents than other ecosystems (Damianidis et al, 2021), suggesting that e.g. monocultural forestry or other UK land use decisions resulting in low biodiversity are a compounding threat (especially, for example, where linked to pest outbreaks and higher levels of mortality, thus providing more combustible standing/fallen deadwood). However, land abandonment can increase wildfire risk if tree planting is not followed by maintenance due to rural abandonment. Social conflicts associated to land used decisions are also a key issue, and can lead to fires being ignited deliberately fires. Note that studies tend to discuss impact of fire on biodiversity, rather than how biodiversity loss may have affected wildfire likelihood, extent and severity (and consequent air pollution effects). See for instance: C40 Cities, 2018; Driscoll et al, 2021 and Kelly et al, 2020 - including context dependency of how fragmentation influences wildfire risk. Air pollution impacts from wildfires occur on a background of chronic air pollution from energy industries and manufacturing (SO_2), domestic combustion (PM2.5), and transport (NO_x) and Agriculture (NH_3) (PHE, 2018b).

Risk title: 2) Algal blooms in water ecosystems
One sentence risk description: Algal blooms reducing water quality in freshwater and marine environments
Risk type: Physical
Risk source and timeframe: Domestic (freshwater) and transboundary (marine), Acute with potentially high repeat frequency
Plausible worst case scenario: Rapid increase in algae and associated cyanobacteria in rivers, lakes and/or coastal areas occurs due to high nutrient levels, increased residence time due to lower flows and freshwater/ocean warming. This is followed by rapid oxygen depletion leading to death of organisms such as fish (Whitehead, et al, 2009). There is potential for lakes to become 'stuck' in turbid rather than clearwater state due to nutrient cycling processes (Scheffer and Carpenter 2003; Hilt et al 2017), changes in flow, the presence of benthivorous fish (EcoShape, 2023) and management practices such as weed-cutting. Increased light availability through clearance of streamside vegetation can increase rate of warming and photosynthesis, while reducing the buffering capacity of the vegetation to stop nutrient input

(JNCC, 2021). Potential impacts include damage to recreational fishing, human health impacts due to toxins produced by cyanobacteria and reduced revenues for retail and service sector in tourism hotspots (e.g. Lake Windermere) - for instance, 75 - 114 million pounds estimated for England and Wales (Pretty et al 2003). If large 'dead zones' are created i.e. hypoxic (low oxygen) conditions, arising from decomposing organic matter from the algal bloom in combination with a stratified water column, then there is potential for impacts on industrial and recreational fishing as seen in Gulf of Mexico (Rabalais 2002). Harmful algal blooms can also impact shellfish production in sea lochs, estuaries and the near coastal zone (Brown et al, 2022).

Rationale for likelihood: Such algal blooms are increasingly documented, although in the marine environment, it is not clear whether they are increasing in frequency; see Hallegraeff 2021. They are exacerbated by warming waters under climate change and nutrient pollution (eutrophication) (Withers et al. 2014; Paerl and Otten 2013), and by lower flows which increase residence times, giving algae more time to grow (Neal et al, 2006; Bowes et al, 2012). In rivers and streams, actions such as riparian tree planting can reduce water temperatures at least for narrow watercourses (e.g. through Keeping Rivers Cool project (Woodland Trust 2016) and reduce nutrient pollution, whereby widescale treeplanting prevents excess nutrients entering the water column (especially if replacing high-nutrient exporting land uses like crop and pastureland) - although there may be subsequent nutrient addition, in an organic form, through leaf fall. Rationale for impact: Algal blooms result in several negative outcomes for the water industry, including the clogging of pipes and filters and the costs of treating affected water. Algal blooms tend to be transitory events and localised, but systems can become stuck in particular states ('ecosystem regime shift'). Impacts on tourism are most likely to occur through a gradual perceived change in the desirability of different destinations from repeated events, particularly in the case of businesses that rely on good water quality, such as campsites near water or watersports facilities. Hence, the economic and financial sector would have some scope to adapt. The material impact will depend on the degree to which the UK government decides to follow recent recommendations (Environmental Audit Committee, 2022) and enforce 'polluter pays principles' (Defra, 2023h).

Compounding threats: Biodiversity; Freshwater pollution; Flooding due to deforestation and soil damage; **North Sea fishery; Ocean acidification;** Risks to tourism; **Aquaculture pest outbreak; Soil health decline; Livestock disease; Global food supply chain interruption;** Business impacts due to UK-only biodiversity policies; Other factors: Residence time, which is controlled by channel gradient, discharge, abstraction and impoundments, has a major effect. Climate change will lower summer flows increasing residence time, whilst higher intensity storms will wash in more nutrients (e.g. Ockenden et al, 2017). Biodiversity loss can make habitats more susceptible to excess nutrient inputs, and to suffer reduced nutrient cycling, leading to more algal blooms. But in general this is an argument not necessarily backed up by evidence. One exception is provided by Eriksson et al 2009 who found that declines in predatory fish promoted bloom forming macroalgae. For the more general argumentation, see for instance Amorim and do Nascimento Moura 2021: "However, due to a high degree of biodiversity loss (e.g. Cardinale et al. 2012) freshwater habitats are becoming more vulnerable to global changes with disastrous consequences to the environment such as harmful algal blooms (Reid et al. 2019)". Other authors (e.g. Reid et al. 2019) do not clearly show this increased vulnerability; rather outlining the emerging threats and persistent conservation challenges for freshwater biodiversity. Most discussion appears to concentrate on how algal blooms harm biodiversity. Some water industry practices can have negative effects, eg. water stored in ponds (e.g. cooling and settling ponds, or to feed canals) can act as injectors of algal innoculums into receiving waters.

Risk title: 3) Biodiversity access and mental health
One sentence risk description: Loss of biodiversity and reduced access to high quality greenspace exacerbating mental health problems
Risk type: Physical
Risk source and timeframe: Domestic, chronic
Plausible worst case scenario: Ongoing loss of biodiversity through habitat loss, invasive species, pollution and climate change, together with a highly urbanized UK population, leads to less 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) (Public Health England 2020). 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). See also the 'extinction of experience': '...a cycle of impoverishment that is initiated by the homogenization and reduction of local flora and fauna, followed by disaffection and apathy. This, in turn, begets more biologically depauperate environments and deeper isolation from nature.' (Miller 2005). Also raises the question that if people no longer value nature or see it as relevant to their lives, will they be willing to invest in its protection?"
Rationale for likelihood: Strong evidence of continued biodiversity loss with the UK described as one of most 'nature depleted countries' (State of Nature Partnership, 2023). Targets exists for reversing biodiversity loss but trends are still for long term decline (State of Nature Partnership, 2023). Large inequalities in capacity to access biodiverse greenspace are also associated with other socioeconomic inequalities (Oliver et al 2022). Clear, UK-based evidence that people derive greater psychological benefit from more diverse vegetated areas, with the general public showing good ability to comprehend diversity, particularly of sessile organisms (Fuller et al 2007). Different components of biodiversity also affect different measures of psychological well-being: plant variety tended to be associated with ability to reflect whereas bird variety was associated with participants' emotional attachments (Fuller et al 2007). More broadly, the number of different habitats in an area tended to correlate with reflection, with a greater diversity of habitats reinforcing personal identity.

Rationale for impact: No clear evidence that the current level of UK biodiversity loss has hampered mental health in a way that has economic impacts - but mental health problems are posited to cost the UK economy GBP 118 billion a year, substantially more than the cost (GBP 70 billion) of providing furlough during COVID (McDaid and Park, 2022). Further research is needed to try and quantify the contribution of biodiversity loss to any decline in mental health. Note though, that there is some evidence that lack of nature in urban areas is associated with less capacity for systems thinking and poorer management of complex problems (Aminpour et al 2022), but pervasiveness and strength of effect is highly uncertain. Presence of vegetation (not necessarily biodiverse - just vegetation) is related to decreased property and violent crime in otherwise similar housing blocks (Kuo and Sullivan 2001). The decreased incidence of violent crime was hypothesized to be related to a less mentally fatigued population with a consequent lower likelihood of resorting to violence; the decreased incidence of property crime was related to likely increases in the actual and implied surveillance of the area with a greater use of more vegetated areas compared to more bare areas by the resident population. Unlikely these examples would scale to loss of financial stability.

Compounding threats: Air pollution from wildfires; **Algal blooms;** Deforestation; AMR; Wildfires; Freshwater pollution; Flooding; Loss of pollinators; North Sea fishery; Ocean acidification; Risks to tourism; Sitka spruce pest; Soil health decline; **Zoonotic disease;** Livestock disease; Acceleration of strict net zero policies; Business impacts due to UK-only biodiversity policies.

Risk title: 4) Direct damage from wildfire
One sentence risk description: Direct damage from wildfire affecting built infrastructure and disrupting transport and communications.
Risk type: Physical
Risk source and timeframe: Domestic, acute
Plausible worst case scenario: Large scale wildfires in UK cause widespread direct damage to buildings, disruption to transport and communication networks and some loss of life/livelihoods.
Rationale for likelihood: Global extreme fires are expected to increase by up to 14%, 30% and 50% in 2030, 2050 and 2100 (UNEP 2022). There is limited spatial association between UK urban population density and commercial forestry (at most risk from fire). In the UK, the wildland-urban interface (WUI) defined as built-up areas with little vegetated cover that are within a certain distance to flammable vegetation is 8850 km2, which represents about 5.34% of the territory (higher than Spain, similar to Greece with 6.66% and smaller than than Italy with around 14%; Bar-Massada et al, 2023). Small scale impacts may well occur in some regions, but low total woodland cover and fragmentation (Riutta et al. 2014) limits risk of fire spread. Rationale for impact: Widespread wildfires that affected deciduous woodland and could spread across landscapes could cause substantial damage to built infrastructure and major impacts on insurance companies. 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, table 4). Insurer risk premia for 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). Disruption of critical infrastructure, transport systems and reduced workforce availability during the acute wildfire phase could exacerbate financial implications. 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 ($125 billion in 2018 dollars) per year on average between 2007–2019 (Borgschulte et al 2023). Damaged/lost assets (timber, housing) may mean high perceived future risk and fire sale of assets.

Compounding threats: Air pollution from wildfires; Biodiversity loss and mental health; Deforestation, Freshwater pollution; **Global food security repercussions; Loss of pollinators; Multiple breadbasket failure;** Risks to tourism; **Sitka spruce pest; Soil health decline; Acceleration of strict net zero policies; Global food supply chain interruption from biodiversity-climate policy misalignment; Housing asset risks; Corporate litigation; Government litigation.**

Risk title: 5) Flooding due to deforestation and soil damage
One sentence risk description: Intensified risks of flooding due to increased frequency of storms/rainfall, or flooding linked to deforestation and soil damage
Risk type: Physical
Risk source and timeframe: Domestic, acute
Plausible worst case scenario: Severe and more frequent climate events such as storms, prolonged rainfall, deforestation and soil degradation cause increased risk of flooding in the UK, leading to increased damage to residential and commercial areas. There will be a larger number of UK homes, businesses and infrastructure facing high flood risk, degrading the environment, damaging critical infrastructure, and increasing flood insurance prices. Landslips caused by flooding and erosion affect buildings in vulnerable zones.

Rationale for likelihood: Currently, there are 5.2 million properties (1 in 6 homes) at risk of flooding and coastal erosion in England. Analysis suggests that climate change will further increase flood risk in the UK (Bates et al 2023). A positive feedback loop exists between deforestation, soil degradation and flood risk (de la Paix et al 2013). Increased deforestation causes soil degradation and both contribute to increased flood risk. These feedback dynamics can lead to flash floods, damaging critical infrastructure, residential properties and the environment. Increased deforestation and soil degradation will likely compound and multiply increased flood risk already expected due to climate change. However, deforestation is currently unlikely given government aspirations and policy commitments to afforestation. The area of woodland in the UK is estimated to be 3.24 million hectares (13% of the UK land area). This represents 10% of the land area in England, 15% in Wales, 19% in Scotland and 9% in Northern Ireland (Sustainable Development Goals 2022). Since the adoption of the Sustainable Development Goals in 2015, woodland area as a proportion of total land area has increased by 2.4% in the UK (an increase of 0.3 percentage points; Sustainable Development Goals 2022). The UK government has made legally binding commitments to increase tree and woodland cover to 16.5% of total land area in England by 2050 (Gov.uk 2022).

Rationale for impact: With increased flood risk severity and extent, it is likely that the price of flood insurance will increase, potentially pricing people out of the market which will leave more people vulnerable to the financial burden of flood damage. The Flood Re program, a public-private partnership to ensure affordable flood insurance in the UK, could help to shoulder the burden of the price increase (Flood Re 2023). However, with greater people in need of assistance, Flood Re might not be a sufficient solution with insurance companies having to put more policies into the scheme and potentially increasing the cost of its own reinsurance program (Flood Re 2023). Furthermore, Flood Re is due to be retired in 2039, which might also leave people more vulnerable to price shocks due to rising flood risk. In the acute phase of flooding, damage to critical infrastructure, such as transportation networks, or damage to businesses, may mean employees have trouble getting to work or businesses have to temporarily close, impacting earnings and risks of defaults on loans. A study on flood risk and house prices found that homes in areas with higher flood risk had lower prices than otherwise expected (Bayes Business School 2023). An extreme case of flooding exacerbated by sea level risk is Fairbourne in Wales, where the local authority has raised the 'decommissioning' of the village, which produced an overwhelmingly negative impact on residents, reportedly causing a sharp drop in house prices by up to 40% and affecting the ability to raise a mortgage, and severely affecting local people's financial and retirement plans, including equity release (Arnall & Hilson, 2023). With more homes across the UK facing flood risk, it is possible that home prices could decrease, potentially increasing the risk of default on loans or decreasing the quality of collateral assets (Bayes Business School 2023).

Compounding threats: Algal blooms; AMR; Biodiversity and mental health; **Deforestation; Freshwater Pollution; Global food security repercussions; MBBF;** Risks to tourism; **Sitka spruce pest; Soil health decline;** Zoonotic disease; Acceleration of strict net zero policies; **Global food supply chain interruption from biodiversity-climate policy misalignment;** Reputational risk, stranded assets and fund withdrawal; **Housing asset risks; Corporate litigation; Government litigation.** Other factors: climate change (increased precipitation), urbanization, inequality.

Risk title: 6) Freshwater pollution
One sentence risk description: Pollution of watercourses, standing waterbodies and ground waters causing health risks
Risk type: Physical
Risk source and timeframe: Domestic, chronic
Plausible worst case scenario: Industrial and domestic effluent and agricultural run-off lead to levels of toxic chemicals and pathogens in watercourses exceeding safe thresholds for human health (DHCS, 2022). These factors are exacerbated by contaminated groundwater used for abstraction, with levels of nitrate being of greatest concern (EA 2018a).
Rationale for likelihood: 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). Environmental regulations in the UK should minimise toxic chemical release, although other issues such as harmful pathogens and anti-microbial resistance are less easy to control and are emerging as contaminants of concern (EA 2018a).

Rationale for impact: Impacts are likely localised and limited (for example bacterial pathogens affecting water users), though potential chronic risk from long-lasting chemicals with unknown effects on health (e.g. endocrine disrupting chemicals, PFAS linked to health impacts etc.) (EA 2018b). Material impacts depend on how progress towards UK Environmental Improvement Plan and other water quality recommendations (UK Parliament, 2022a). Exposure and impact are highly uncertain and likely to be gradual, giving financial systems time to adapt.

Compounding threats: Algal blooms, AMR, Biodiversity loss and mental health; Wildfires; **Flooding due to deforestation and soil damage;** Risks to tourism; Soil health decline; Ocean acidification; Risks to tourism; Soil health decline; Zoonotic disease; **Livestock disease;** Business impacts due to UK-only biodiversity policies; **Housing asset risks; Corporate litigation; Government litigation.** Other factors: Drought can increase the incidence of waterborne diseases such as diarrhoea and gastroenteritis as a result of reduced water for cleaning, sanitation and personal hygiene (Stanke et al 2013; Bifulco and Ranieri 2017), while reduced summer flows and evaporation lead to concentration of toxins in watercourses and standing water bodies. Biodiversity loss (as well as removal of natural vegetation) may impact ability of terrestrial habitats to intercept pollutants prior to reaching water (as nutrient use efficiency is expected to be greater in more biodiverse habitats). Biodiversity loss within (surface) freshwater systems may lead to increased prevalence of deleterious organisms for human health due to lack of natural enemies. Research tends to concentrate on how freshwater pollution compromises freshwater biodiversity (e.g. Williams-Subiza and Epele 2021; Reid et al 2019) so it is difficult to assess to what extent the risk of freshwater pollution is exacerbated by biodiversity loss.

Risk title: 7) Housing asset risks due to policy and legal changes
One sentence risk description: Strict planning regulations create significant asset, underwriting and credit risks for housing developments and additional costs for homeowners.
Risk type: Transition
Risk Source and timeframe: Domestic, chronic
Plausible worst case scenario: Strict planning regulations (e.g. for nutrient pollution and biodiversity net gain), government policy and legal changes create significant asset, underwriting and credit risks for housing developments. Strong adoption of the UK 25 Environment Plan and the Kunming-Montreal Global Biodiversity Framework (CBD, 2023), constrains the land availability to meet the needs of a growing population and worsens the housing crisis, particularly in high-population growth regions of southern England. This affects labour mobility and, in turn, UK productivity. In addition, these increase pressure on households and result in both a wealth effect (decrease in consumption due to lower wealth) and a negative effect on debt repayment. A lack of housing leads to high demand which in turn can lead to higher mortgages and higher risks of mortgage defaults impacting exposed lenders. This is exacerbated by net zero transition risks, whereby government policy or legal changes require homeowners to invest in upgrades to their property, including requirements to pay for improvements to their properties. If properties are not upgraded to sufficient standard they are subject to valuation haircuts. These policies for minimum energy efficiency standards affect asset repricing and may impact the macro-economic variables, resulting in further financial difficulty for the customers which may increase the risk of credit losses.

Rationale for likelihood: Biodiversity net gain legislation will be introduced in early 2024 (Defra, 2023), and the House of Lords did not support a Bill which would have ensured housing development could proceed in areas currently affected by nutrient neutrality (DLUCH, 2023).

Under the current UK government the likelihood of strict measures that cause significant damage to the housing industry is low. However, this could change depending on a significant change in government. Population in England is expected to grow by 5% (ONS, 2020a) and households by 7.1% (ONS, 2020b) between 2018-2028. Between 1990 and 2015 "2,505km2 of grassland (about the size of Dorset) and 1,121 km2 of arable farmland (almost the size of Bedfordshire) were converted to urban use" (UKCEH, 2020).

Further housing expansion may be slowed on the basis of biodiversity impacts and also concerns about the loss of high-grade agricultural farmland, which could worsen UK food security. The UK government's Minimum Energy Performance of Buildings Bill required all new tenancies to have an energy performance certificate rating of Band C or above starting from 2025 and the new regulations will apply for existing tenancies in 2028 with financial penalties for non-compliance. However all of these EPC changes have now been scrapped and instead the Government will now encourage landlords to upgrade the energy efficiency of the property where possible.

Rationale for impact: Lack of access to suitable housing impairs labour mobility (House of Commons, 2023). Productivity levels are negatively affected by housing shortages (Economics Observatory, 2023; Bank of England, 2022; The Developer, 2022). The economic outlook is increasing pressure on UK household debt repayment (Bank of England, 2022).

Compounding threats: Deforestation; Wildfires; Freshwater pollution; Global food security repercussions; Flooding; Soil health decline; Zoonotic disease; **Net zero policies; Reputational risk, stranded assets and fund withdrawal; Corporate litigation; Government litigation.** Other factors: Flooding, regulatory change, urbanisation and demographic change.

Risk title: 8) Risks to tourism from nature damage
One sentence risk description: Damage to UK biodiversity impacts domestic and international tourist numbers
Risk type: Physical
Risk source and timeframe: Domestic, chronic with acute phases
Plausible worst case scenario: Damage to nature from habitat and biodiversity loss, pollution (air and water), flooding, wildfire and over-development leads to a collapse of domestic and international visitor numbers to regions with a high tourism dependency. This leads to impacts on local economies with tourism sectors SMEs folding and defaulting on loans. Could be an acute shock if numbers drop off due to impacts such as zoonotic disease, wildfires or flooding.

Rationale for likelihood: In 2013 the MCCIP outlined several likely impacts on tourism and marine recreation including flooding and coastal erosion resulting in loss of beaches and habitats; disruption to transport infrastructure; rising sea temperatures causing health risks through marine pathogens and harmful algal blooms and warmer temperatures resulting in increased visitor numbers and opportunities but also corresponding burden on coastal communities' infrastructure (Coles, 2020). However Coles (2020) states that these have not been updated in light of recent advances in research into climate and environment (Coles, 2020). Human zoonosis epidemics (DCMS, 2021) and wildfires (Otrachshenko and Nunes 2022) both strongly impact tourism. Acute shock from human zoonotic disease would result in sharp decline followed by likely slow recovery, with coastal areas likely to be more severely affected (ONS 2021a; Liu et al. 2023). A recent study of Portugal estimated that the annual costs to Portuguese tourism from wildfire will increase at least fourfold by 2050 (Otrachshenko and Nunes 2022) (currently standing at €17-24 million for domestic tourist arrivals and €18-38 million for international tourists).

Rationale for impact: In 2018 the UK attracted 38 million international visitors, who added £23bn to the economy, making tourism one of the country's most important industries and the third largest service export (HM Gov Industrial Strategy, 2019), accounting for 3.1 million jobs in 2017 (Coles, 2020). Current forecasts predict the sector will deliver a 23 per cent increase in inbound visitors by 2025. Domestic tourism is also set to increase by an estimated 3 per cent per annum until 2025. In 2018, British residents took 119 million overnight trips in the UK, totalling 372 million nights away and spending £24bn. Nature contributed an estimated £12 billion to tourism and outdoor leisure within the UK in 2019 (ONS 2021c). Outside urban areas, coastal margins, enclosed farmland and marine environments see the greatest number of visitors. However, ironically, the majority of the amount spent and number of activities completed during tourism and outdoor leisure visits within Great Britain took place in an urban setting.

Expenditure within urban locations has risen from £4.6 billion in 2011 to a high of £7.3 billion in 2019. Within the same period, all other habitats have seen expenditure fall, despite an increase in the total amount being spent (ONS 2021c). For outdoor activities, the largest share of expenditure took place whilst walking, running and cycling (£3.6 bn in 2018), followed by sightseeing (£1.7 bn) and watching wildlife and visiting parks and gardens (£1.6bn). Overall, tourism and outdoor leisure asset value is estimated at £482 bn in 2019 (ONS 2021c). Wildlife tourism is particularly important in Scotland (NatureScot, 2010) contributing about 40% of all 40% of all tourism spend, and supporting 39,000 full time equivalent jobs.

Compounding threats: Air pollution from wildfires; Algal blooms; Biodiversity and mental health; Wildfires; Freshwater pollution; Global food security repercussions; Flooding; MBBF; North sea fisher collapse; Ocean acidification; Sitka spruce pest; Soil health decline; Zoonotic disease Livestock disease; Net zero policies; Global food supply chain interruption from biodiversity-climate policy misalignment; Business impacts due to UK-only biodiversity policies; Corporate litigation; Government litigation.

Risk title: 9) Water shortages impact energy and agriculture
One sentence risk description: Water shortages in rivers, standing water bodies and in groundwaters lead to reduced agricultural productivity and impact energy supply and prices.
Risk type: Physical
Risk source and timeframe: Domestic, chronic with acute episodes
Plausible worst case scenario: Climate change leads to severe periods of soil-moisture deficit which reduce quality and yield of crops, such as potatoes, onions, carrots, apples, as well as water use restrictions impacting livestock production. Demand for water for industry places further limitations on the potential for abstraction for agricultural limitation, meaning UK agricultural productivity is severely limited during increasingly frequent drought prone years. Extreme droughts lead to interruption of electricity generation through availability of water for cooling and hydroelectric power generation, leading to imbalances of supply and demand and forced shutdown of 'non-essential' industries during extreme periods. The UK National Risk Register (2024) suggests that a reasonable worst-case scenario is based on large parts of South and East England facing severe drought conditions after three consecutive dry winters. Neighbouring areas of the Midlands and South West would face drought-related impacts and there would need to be public water supply restrictions. There would be significant losses to the UK economy, with serious impacts on industry, agriculture and businesses.

Rationale for likelihood: By 2050, changes in supply due to climate change and changes in demand due to population growth is projected to lead to deficits across many water resource zones in the UK. The manufacturing sector's demand for water could be 400% higher by 2050 than in 2000 (MoD, 2018). The vast majority of zones impacted would be in England, with those in the south east the worst affected (HR Wallingford, 2020). 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). The Environment Agency (2021) highlights overuse of water already across several catchments in central/SE England and high water stress. Numerous thermoelectric power stations across the world have already faced output reductions and shutdown due to either cooling water that was too warm or insufficient in volume (Byers et al., 2015), while evidence of the water shortage impacts on agriculture is extensive (e.g. FAO 2017b). Demand-side adaptation actions (e.g. reducing household and industry use and addressing network leakage) alone are unlikely to be sufficient to solve the deficits faced in all water resource zones. Inter-regional UK transfers may not be sufficient to ensure secure water supplies between regions (HR Wallingford, 2020).

Rationale for impact: 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, 2023a) estimated the value of their equivalent 'water abstraction' ecosystem service to the UK at £5.4 billion in 2021 prices. Experience of recent years highlights the UK's susceptibility to drought, with economic impacts on energy and agriculture in particular. 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.

Abstractions of water from freshwater bodies are regulated to allow fair allocation of water between competing demands (including municipal water supplies and agriculture, as well as cooling water). Impacts of water shortages can be mediated through multiple channels, several notable ones being : (1) increasing in electricity prices linked to water scarcity to the power sector (a sector reliant on abstraction), (2) increased costs to households and firms due to rising water bills associated with increased investment from water companies and (3) increasing food prices and/or reduced agricultural productivity related to reduced abstraction. In the UK, thermoelectric capacity provides 96% of electricity supply (Byers et al., 2015), and around 20% of electricity production relies on freshwater-cooled power stations. A probabilistic spatial risk model of regional climate, hydrological droughts and cooling water shortages, coupled with an economic model of electricity supply found that annualized cumulative costs on electricity prices in Great Britain range from £29–66M per year (2018 GBP values). Under climate change the median annualized impact is expected to exceed £100M per year. The single year impacts of a 1-in-25 year event exceed >£200M (Byers et al., 2020). Hydroelectric energy is a much smaller component of the UKs energy mix (around 2%) and is affected by lower flow rates. However, droughts that are more wide-scale than the UK may push up prices of gas and imported electricity still further, which has a knock-on effect on the wholesale price of energy in Britain. Changes in water availability that reduce the generating capacity of hydropower plants can hinder the transition to a low-carbon economy, and failing to account for these risks in forward-looking risk assessments could lead to a rapid financial revaluation of the firms and economic activities exposed to such risks (Senni et al, 2023). Total projected costs to the UK economy from drought vary widely. One approach using a dynamic national water resource systems model with a static economic input-output (I-O) model to assess total drought risk to the economy suggests a direct Expected Annual Loss (EAL) to water users in England and Wales to be £11.7 million in the 2011 base-year. Accounting for indirect economic losses this results in a total EAL of £30.2 million in 2011. The most severe event simulated results in a total loss of £1.4 billion in 2011, equivalent to 0.11% of GVA (Jenkins et al, 2021). Water UK (2016) estimated that for England and Wales as a whole there could be up to a 37% loss in Gross Value Added (GVA) if Level 4 restrictions were applied to all business and non-household public sector water users, equivalent to £1.4 billion per day.

Water shortages already impact UK agriculture and, although plans are in place to assist adaptation (e.g. AHDB 2024, Defra 2023i), impacts on agricultural productivity and business viability are expected to grow. Long term effects of water shortage on UK agriculture could lead to food insecurity impacts, but this is highly contingent on availability of supplies from elsewhere (Defra, 2021). Long-term trends in import-dependency are uncertain, but it is clear that sub-sets of the UK population would be more vulnerable (Bryan et al, 2020). Sustained droughts impact on food prices. For example, during the 2018 drought in the UK, reduced crop yields contributed to a considerable increase in the price of animal feed, and input costs for livestock products were as high as 20% to 25% more for some farmers (Salmoral et al. 2022). This led to some farmers having to sell livestock, reduce herd sizes and reduce the amount of animal products produced, which in turn led to increased prices of animal products (such as meat and milk) passed on to the consumer (Salmoral et al. 2022; UKHSA, 2023b). Note, there may be additional impacts of drought on human health, for example increased contamination of drinking water supplies. Water companies have drought plans in place to prevent supply issues, but private water supplies are particularly vulnerable during drought periods (in England, 1% of the population get their water from private water supplies, compared with 3% of the population in Wales and Scotland; UKHSA, 2023b). Biofuel production can additionally compete with agriculture for both land and water resources (Fraiture et al, 2008).

Compounding risks: Not assessed

Mainly International risks

Risk title: 10) Critical resource supply chain disruption
One sentence risk description: Supply chain disruptions of key aspects of natural capital (such as critical minerals) lead to shortages for manufacturing sector and industry impacts
Risk type: Physical
Risk source and timeframe: Transboundary, chronic with acute episodes
Plausible worst case scenario: Disruptions of key minerals such as those occurring as a consequence of increasing global demand (e.g. for net zero transition) in combination with acute disruption affecting key trade routes from extreme weather events and geopolitical disruptions. These disruptions are exacerbated by a break down in free trade and increased market protectionism, leading to shortages for manufacturing firms, increasing prices and hampering economic growth.

Rationale for likelihood: Global demand for raw materials is rising due to increasing disposable incomes around the world (McKinsey, 2016). In addition, demand for critical minerals is driven by the energy sector and a shift to clean energy technologies (IEA, 2023). For example, lithium supply is estimated to fulfil only half of projected requirements to meet 2030 climate goals (IEA, 2021). Total mineral demand globally for clean energy technologies is expected to rise by 4 - 6 times by 2040 (IEA, 2021). 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). 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), while geopolitical tensions in turn may further disrupt free trade. Countries have already been using export taxes and quotas to manipulate volatile markets, exacerbating supply issues, as demonstrated by export restrictions on gallium and germanium, key elements in microchips and fibre optics (94% of the world's gallium is produced in China and 4% in Russia; Dept. Business and Trade, 2023).

Rationale for impact: Our economy relies on access to critical minerals; from cobalt, lithium, and graphite for batteries; silicon, tin, and gallium for our electronics; to rare earth elements for electric motors (Dept. Business and Trade, 2023). In the UK, eighteen minerals and metals have a 'high' potential criticality rating in terms of their global supply risk and the UK economic vulnerability to such a disruption, and constitute the UK Critical Minerals List 2021 (BGS, 2022). Rising mineral prices increase the cost of clean energy technologies and slow their deployment (IEA, 2022). Geopolitical disruption has been shown to worsen supplies; for example the war in Ukraine resulted in disruption to global supplies of nickel, leading to price rises of 270%, causing the London Metal Exchange to suspend trading (London Metal Exchange, 2023). The UK imports most of its critical minerals and faces international competition for key resources (UK Parliament, 2019). As a consequence of global shortages, industries heavily dependent on critical minerals will be affected, potentially leading to higher prices and job losses. High risk minerals such as tellurium and rare earth elements, needed for solar power and wind turbines, if harder to source will drive up prices with impacts on consumers. The UK government and industry are already working to adapt to supply chain disruptions (Dept. Business and Trade, 2023), while reducing waste, recycling and increasing circularity of the economy will help to lower, but by no means eliminate, dependencies.

Compounding risks: Not assessed

Risk title: 11) Deforestation and ecosystem tipping points
One sentence risk description: Deforestation driving tipping points in major global forest ecosystems (e.g. Amazon, boreal forests), which leads to acceleration of global heating.
Risk type: Physical
Risk source and timeframe: Transboundary, chronic leading to acute
Plausible worst case scenario: Deforestation for food production (e.g. cattle ranching in Amazon) combined with climate change (e.g. drought) leads to ecological tipping of forest ecosystems into savannah ecosystems with major consequences for regional weather (e.g. reduced rainfall hampering crop production), local flooding and landslides, and acceleration of global heating. As a consequence, major impacts on global food insecurity as well as direct climate impacts (e.g. extreme weather events).
Rationale for likelihood: The likelihood of the tipping point occurring in the 21st century is unclear, ranging from 'low' according to the IPCC to 'high' in recent papers. Many studies show that in the absence of other contributing factors, 4° C of global warming would be the tipping point to degraded savannas in most of the central, southern, and eastern Amazon (Lovejoy and Nobre, 2018). However, widespread use of fire to eliminate felled trees and clear weedy vegetation leads to drying of surrounding forest and greater vulnerability to fire in the subsequent year. Interacting drivers may lead to tipping points in ecosystems being achieved much faster than under single drivers (Willcock et al. 2023). Estimates are that negative synergies between deforestation, climate change, and widespread use of fire could lead to a tipping point to non-forest Amazon ecosystems in at 20-25% deforestation (Lovejoy and Nobre, 2018). In 2017 more than 13% of the Amazon's old-growth forest had been cleared, largely for ranching and for growing crops (Nature, 2023). Boreal forests are also affected by logging, wildfires and hotter and drier conditions reducing tree growth (D'Orangeville, 2023).
Rationale for impact: The Amazon dieback is considered one of the major global ecological tipping points that could cause runaway (positive feedback) climate impacts (Lenton, 2019). Amazon dieback could release another 90 Gt CO2 into the Earth's atmosphere. There is high confidence that climate change will increasingly add pressure on food production systems (Ritchie et al, 2020), undermining food security, water security and driving human displacement (IPCC AR6, 2022). Additionally, Europe faces climate-related risks to economies and infrastructures from coastal flooding, stress and mortality from heat extremes, and marine and terrestrial ecosystem disruptions (IPCC AR6, 2022).

Compounding threats: Air pollution from wildfires; Biodiversity and mental health; **Wildfires; Global food security repercussions; Flooding; Loss of pollinators; MBBF; North Sea fishery collapse; Ocean acidification; Aquaculture; Sitka spruce pest;** Zoonotic disease; **Livestock disease; Acceleration of net zero policies; Global food supply chain interruption from biodiversity-climate policy misalignment;** Reputational risk, stranded assets and fund withdrawal; **Housing asset risks; Corporate litigation; Government litigation. Other factors:** Climate warming impacts of forest ecosystem stability, disruption of Atlantic Meridional Overturning Circulation (AMOC) could also dry the Amazon, extreme events such as wildfires haste ecosystem regime shift. Others include changes in land-use activity, forest fires, edge effects, agricultural expansions, forest degradation, climate change, ecosystem degradation.

Risk title: 12) Global food security repercussions
One sentence risk description: Mass human displacement both within and between countries prompted or exacerbated by food insecurity
Risk type: Physical
Risk source and timeframe: Transboundary, chronic with acute phases
Plausible worst case scenario: Irregular migration in the UK increases drastically as a result of major food crises across the world, further exacerbated by extreme climate events and geopolitical turmoil. From a starting point of 50,000 per year in 2023 (in Home Office, 2023b) numbers of irregular migrants increases over tenfold over the next decade, leading to major costs for border control and the UK health care system with potential for civil unrest around both the treatment of refugees and disruption of local community services.
Rationale for likelihood: Continued growing international flows of refugees are predicted to occur in coming years (UNHCR 2022), with the potential for very large numbers under extreme climate change. According to a 'middle of the road' (SSP2-4.5 pathway) reference scenario 2.0±0.2 billion people could be living in areas outside of the historical habitable 'human climate niche' by 2030 and, in the absence of novel adaptation measures to survive heat, would need to migrate out of these areas (Lenton et al 2023). The total number of international migrants increased by more than 40% between 2000 and 2027, and is expected to be over 400 million by 2050 (FAO, 2017a), with subsequent increases in irregular migration to the UK (Home Office, 2023b). Drivers of immigration include conflict, poverty, food insecurity, lack of employment, and effects of environmental degradation and climate change (MoD, 2018; Challinor et al. 2016). This is likely to be exacerbated by population growth in parts of the world that may suffer the greatest impacts of food insecurity and climate change.

Rationale for impact: Analysis of fiscal implications suggests the average UK-based migrant from Europe contributed approximately £2,300 more to UK public finances than the average UK adult while each non-European migrant contributed over £800 less than the average (Oxford Economics, 2018). Distress migration in particular can pose significant challenges. Many migrants undertake difficult and dangerous journeys resulting in loss of life; 59,037 deaths during migration have been recorded since 2014 (Migration Data Portal, 2023). Migrants also experience difficult conditions in their countries of destination, for instance, higher levels of unemployment (Eurostat, 2023). Dealing with increased refugee flows as a consequence of worsening global food security is likely to be a major cost for governments. Home Office documents suggest the increase in individuals illegally crossing the UK border is putting financial and economic pressures on UK Border Force, the UK asylum system, wider public sector spending, and local services' capacity and capability under existing processes (Home Office, 2023a). Under very large migration numbers health systems may be overwhelmed and local economies disrupted, including risks of civil unrest.

Compounding threats: AMR; **Deforestation; Wildfires; Flooding; Grain crops pest/pathogen, Flooding; Loss of pollinators; MBBF; North sea fishery collapse; Ocean acidification;** Risks to tourism; **Soil health decline;** Zoonotic disease; Livestock disease; **Net zero policies; Global food security repercussions;** Business impacts due to UK-only biodiversity policies; **Housing asset risks; Government litigation.** Other factors: Biodiversity loss increases the likelihood of migration flows caused, in this scenario, by climate change. In general biodiversity is expected to help foster resilience to climate change and help buffer the worst consequences, e.g. greater range of crop variety means there is more likelihood that a given crop will provide food and thus reduce need to migrate (though, there is also evidence that farm and livelihood specialism can quicken recovery from extreme weather impacts, Thompson et al. 2023). Intact ecosystems provide buffers against climate change impacts such as sea level rise and storm surge, protecting land and allowing its continued use. The use of nature-based solutions may allow adaptation and change in a way that may be difficult if using a hard engineered solution that could fail after a certain degree of change.

Risk title: 13) Global food supply chain interruptions from biodiversity and climate policy misalignment
One sentence risk description: Major global food supply chain interruptions related to biodiversity protection and misalignment with climate change cause food insecurity
Risk type: Transition
Risk source and timeframe: Transboundary, chronic with acute phases.
Plausible worst case scenario: Global supply chains are disrupted as governments implement stricter environmental policies and internalise hidden costs of food production (FAO, 2023) in the face of growing physical risks. Global food supplies are reduced leading to re-adjustment of export partners and import shortages in some countries. Food shortages are exacerbated by physical risks such as soil health declines and pollinator loss, as well as extreme weather events such as flooding and drought from worsening climate change. Growing geopolitical strife on a worsening environmental backdrop leads to more protectionist policies and a focus on domestic food security, with countries implementing export bans. Food is increasingly used as a geopolitical weapon. Food prices spike and remain highly volatile for several years before chronic shortages set in. Acute phases of food shortage lead to widespread civil unrest in multiple urban centres, disrupting labour availability, transport and interruption of financial operations and causing political turmoil (UK-CRP 2023; MoD, 2018).

Rationale for likelihood: The Global Food Security Index Report suggests global food security made gains from 2011-2015 but since then continues to deteriorate (The Economist, 2022). Shocks are more frequent and extensive, further weakening an already-fragile global food system. FAO have identified a range of future global food scenarios to 2050 (FAO, 2018, with uncertainty substantial, but they suggest if the entire range of production and consumption costs is taken into account, including resource degradation and GHG emissions, evidence indicates that food prices are likely to increase "significantly". The UK has a high import dependency and currently produces about 60% of its domestic food consumption by economic value, part of which is exported (Defra, 2021). However, from a balanced dietary perspective our self-sufficiency is likely lower, meaning that the UK is vulnerable to global supply chain disruption. Overall, 80% of the UK's food supply comes from domestic sources or imports from Europe. The remainder is mostly spread between Africa, Asia, North America, and South America (Defra, 2021). Supplies of long-life food in the country are reasonably high meaning that short periods of food supply disruption would unlikely cause significant civil protest, but extended disruptions over weeks could do so. The UK Ministry of Defence in their Global Strategic Trends 6 report suggest that in the coming decades, some countries may be tempted to deliberately limit supplies of scarce resources for geopolitical gain (resource nationalism) and tension over resources, possibly including military action to secure supplies, cannot be ruled out (MoD, 2018). These conflicts could escalate over shortages of critical minerals, food or water and there may be synergistic effects of these problems (e.g. recent CO2 shortages affecting food sector). The MoD suggests there could also be knock-on effects for worldwide stability, as higher food prices, in combination with poor governance, have been shown to heighten the risk of protests, riots and conflict (MoD, 2018). Food insecurity may create grievances that escalate into instability and violent conflict, acting as a channel for individuals or groups to express broader socio-economic and political grievances (SIPRI, 2021). Recent research highlights disruption to the UK food system as a potential key driver of civil unrest (Jones et al 2023). Using a scenario backcasting approach and by defining as an end-point a societal event in which 1 in 2000 people have been injured in the UK, Jones et al (2023) found that 38% of experts rated this outcome as "Possible" over the coming decade, increasing to 80% of experts over a timeframe of 50 years.

Rationale for impact: Work by the Chatham House think tank describes how an outbreak of protectionism affecting the key food commodities – or fertilizers – could lead to price shocks, ecological damage, and the undermining of food security for some of the most vulnerable populations (Chatham House, 2017). They describe how the consequence of a rise in protectionist policies on a global scale is likely to manifest itself as a significant upwards driver of prices. In the short-term, in well-supplied markets, prices may fall if producers face barriers to selling their produce, but when stocks are lower and harvests are poorer protectionism is likely to be a strong upwards driver of prices, as witnessed during the 2007-08 and 2010 food crises. Household food security could face long-lasting impacts, as price transmission from international markets is often 'sticky' – meaning that domestic prices remain elevated even when international prices ease (Chatham House, 2022b). In January 2022, one in 10 adults in the UK experienced food insecurity (meaning that they skipped meals or went a whole day without eating). About 30 per cent of the global population lacked access to adequate food in 2020 (Chatham House, 2022b). Perceptions of unjust policymaking, of weak governance or political instability can foment social unrest; the food price spikes of 2007–08 and 2010–11, and energy price spikes in 2007–08 and 2011–13 all resulted in riots. These in turn can further undermine governance and have the potential to lead to state failure (Chatham House, 2022b), with international ramifications. Current geopolitical events such as the Ukraine war set a worsening backdrop of global food security which could cause civil unrest. Analysis by Allianz Research identified 11 large emerging markets that face a high risk of food-related unrest in the next few years: Sri Lanka, Algeria, Bosnia and Herzegovina, Egypt, Jordan, Lebanon, Nigeria, Pakistan, the Philippines, Tunisia, and Turkey (Allianz, 2022). In the UK, 2021/22 saw 2.2 million emergency food parcels handed out by the Trussell Trust, which is a tenfold increase from 10 years earlier (UK Parliament, 2022c). UK civil unrest and riots would mean severely reduced labour productivity/availability over a period of multiple days/ weeks affecting all sectors. Property could be damaged and critical infrastructure and supply chains could be damaged/disrupted.

Compounding threats: Algal blooms; AMR; **Deforestation; Wildfires; Grain crops pest/pathogen; Global food security repercussions; Flooding; Loss of pollinators; MBBF; North Sea fisheries; Ocean acidification; Aquaculture pest outbreak;** Soil health decline; Zoonotic disease; **Livestock disease; Net zero policies; Corporate litigation; Government litigation.** Other factors: High levels of poverty and existence of vulnerable populations, trade disruption due to geopolitical shocks. More rapid climate change worsens global food security as does biodiversity loss (UK Parliament, 2022d).

Risk title: 14) Multiple breadbasket failure (MBBF)
One sentence risk description: 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.
Risk type: Physical
Risk source and timeframe: Transboundary, acute
Plausible worst case scenario: Janetos et al. (2017) define multiple breadbasket failure (MBBF) as 'a major yield reduction in annual crop cycle of a breadbasket region where there is a potential impact on global food systems because: a) the production area is critical to global commodity trade; b) the area provides food for a significant proportion of the population at local, regional, national, or global scales; c) the area provides food such that a crop failure may have significant consequences in humanitarian, economic or political dimensions'. Vulnerabilities arise due to the structure of globalized food systems – a failure in one region can have implications that spread rapidly in non-linear ways. Four major drivers of pressure on global food systems: population growth and urbanization; increasing transition to meat-based diets (grain-fed animal products); climate change (water availability and heatwaves) and increased globalisation and merging of agricultural commodity markets, increase vulnerability to systemic risk (Janetos et al. (2017). The immediate consequences of MBBF for the UK are increasing prices, shifting of consumer preferences, and a change in domestic agricultural practices to meet demand. Depending on severity and context MBBF may also result in health impacts, civil unrest and geopolitical crises including human migration. At the global level, developing countries increasingly turn to developed markets for food supplies, and developed countries likely introduce export bans and people would resort to large-scale hoarding. This causes a negative feedback loop, amplifying shortages and price increases (Chatham House, 2021).

Rationale for likelihood: Literature points to evidence of rising risks of 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). Note, the latter is contradicted by other work which finds increase in risk of synchronised failure of rice crops between 2001-2008 (Mehrabi and Ramankutty, 2019).

Rationale for impact: Literature points toward potential fluctuations in production of the main cereal crops of between 15 and 30% for one year, albeit underlining the significant uncertainty in this. These annual deviations are within the boundaries of historical deviations, though studies suggest an increasing risk of synchronized impacts occurring. Historical examples include the 2010 drought in Russia and Ukraine which contributed to a 27% increase in global wheat prices (Janetos et al. (2017). Early estimates of climate change impacts combining climate, crop and economic models find an average 17% decline in yield for the four major crop groups of coarse grains, oil seeds, wheat, and rice, with consequent economic shocks including price increases of 20%, intensification of agriculture (area increase) and a 3% decline in consumption (Nelson et al. (2014). These models, however, may underestimate yield responses to droughts and heatwaves (Heinicke et al, 2022). Impacts vary across regions depending on wealth and level of dependence on imports (Janetos et al. (2017). Recent research highlights disruption to the UK food system as one of the key drivers of civil unrest (Jones et al 2023).

Compounding threats: Deforestation; Wildfires; Grain crops pest/pathogen; Global food security repercussions; Flooding; Loss of pollinators; North sea fishery; Ocean acidification; Risks to tourism; **Soil health decline;** Zoonotic disease; **Livestock disease; Net zero policies; Global food supply chain interruption from biodiversity-climate policy misalignment;** Business impacts due to UK-only biodiversity policies; Reputational risk, stranded assets and fund withdrawal. Other factors: Extreme weather (Drought, flooding) - experts have documented how systemic cascading climate risks are likely to lead to food insecurity geopolitical factors - e.g. reduced Ukraine wheat production **(Chatham House, 2021).** A number of factors were identified that might be expected to amplify food shortages and price increases including animal and plant diseases contributing to crop failures, hunger and malnutrition, alterations of livelihoods and resulting poverty that drive societal tensions, migration and conflict.

Risk title: 15) Ocean acidification
One sentence risk description: Dissolved CO2 in oceans increases acidity, decreasing ocean pH, and affects marine ecosystems
Risk type: Physical
Risk source and timeframe: Transboundary, chronic
Plausible worst case scenario: Ocean acidification leads to degradation and eventual collapse of shellfisheries and other fisheries due to decline in certain zooplankton and knock-on consequences for food webs around UK waters. Acidity transfer from shallow to deeper water impacts on marine species and ecosystems at greater depths such as cold water coral reefs - occuring around the UK shelf and NE Atlantic at depths from 200 to 1500m. This reduces the availability of protein sources for human consumption. Shellfish are directly affected due to acid conditions, but the consequences on food webs also impact a wide range of ocean fish, with economic consequences on these industries. Under high GHG emission scenarios, c. 60% of bottom waters on the NW European shelf become permanently corrosive to soluble forms of CaCO3 (e.g. aragonite) and episodic corrosive conditions begin as soon as 2030 (MCCIP, 2022). This is known as undersaturation, and it is predicted that by 2100 up to 90% of the north-west European shelf seas will experience undersaturation for at least one month of each year (Murray et al 2022) thus having implications for shellfish shell formation and economic consequences.

Rationale for likelihood: In 2020 the surface ocean was approximately 40% more acidic than pre-industrial levels. Locally the North Atlantic Ocean contains more anthropogenic CO2 than any other ocean basin due to deep water formation that occurs there, which effectively transfers CO2 from the surface to the ocean interior (MCCIP, 2022). There is already evidence of ocean acidification affecting shell integrity of plankton calcifiers. A recent 3-year study in the northern North Sea supports the relationship between natural variability in seawater Aragonite (a crystal form of calcium carbonate) and shell integrity in pelagic gastropods (León et al., 2020). This raises valid concern around the potential consequences for bivalves and crustacean populations in the North Sea and for future implications for the shellfish and aquaculture industry. By 2060, around 85% of known deep-sea cold-water coral reefs in the UK could be exposed to waters that are corrosive to them (Jackson et al., 2014). Note that evidence for deep water impact is based on experimental work (Murray et al 2022). Impacts are likely to be heterogeneous given ocean acidification not spatially homogeneous (Artioli et al 2014) reducing the likelihood of a widespread decline in shellfish. As shown in (Murray et al 2022), impacts will not be evenly distributed - the rate of pH decline in coastal areas is projected to be faster in some compared to others e.g. Bristol Channel vs Celtic Sea. The knock-on consequences on biota are poorly understood, even though the physico-chemical impacts are well-understood (Murray et al 2022; Le Quesne and Pinnegar 2022).

Rationale for impact: The United Kingdom produces around 0.9 million tonnes of fish per year (including molluscs and crustaceans), with a value of USD 2667.2 million, with 50% of this arising from wild caught fish **(OECD 2021).** Ocean acidification is estimated to lead to direct potential losses due to reduced shellfish production ranging from 14% to 28% of fishery net present value by 2100 **(Mangi et al, 2018; MCCIP, 2022).** The slow chronic onset does give time for adaptation among sectors. However, there could be knock-on consequences for exports and tourism if artisanal fisheries are lost.

Compounding threats: Algal blooms in water ecosystems; Biodiversity loss and mental health; **Deforestation;** Freshwater pollution; **Global food security repercussions; Multiple breadbasket failure;** North sea fishery collapse, Risks to tourism from nature damage; **Aquaculture pest outbreak; Global food supply chain interruption from biodiversity-climate policy misalignment;** Business impacts due to UK-only biodiversity policies; Government litigation; Other factors: Climate warming - there is some evidence that warming temperatures actually reduce the extent of ocean acidification due to less dissolution of CO2, while colder temperatures and higher pressure make CO2 gas more soluble at deeper ocean depths (Teng et al 1996). Biodiversity loss may exacerbate the impact of ocean acidification, but most studies concentrate on how ocean acidification is affecting biodiversity. The complex interactions between autotrophs, habitat-forming species and biodiversity is yet to be fully understood (Murray et al 2022). Initial work suggests that high biodiversity can ameliorate some of the more negative impacts of sensitive species (Rastelli et al. 2020). Rastelli et al. suggest that: "at higher biodiversity, the impact of acidification on otherwise highly vulnerable key organisms can be reduced by 50 to >90%, depending on the species." They show that such a positive effect of higher biodiversity can be associated with higher availability of food resources and healthy microbe-host associations, overall increasing host resistance to acidification, while contrasting harmful outbreaks of opportunistic microbes. Given climate change scenarios predicted for the future, they conclude that biodiversity conservation of hard-bottom ecosystems is fundamental also for mitigating the impacts of ocean acidification (Rastelli et al. 2020).

Both Domestic and International risks

Risk title: 16) Acceleration of strict net zero and nature protection policies
One sentence risk description: UK acceleration of strict net zero and nature protection policy, with misalignment within UK and between countries
Risk type: Transition
Risk source and timeframe: Domestic and transboundary, Chronic
Plausible worst case scenario: There is disorderly and divergent policy implementation to achieve net zero goals, restore UK environmental quality and mitigate transboundary risks from climate change. Defra outlined an Environmental improvement plan for restoring biodiversity, water quality, air quality and biosecurity (DEFRA 2023a). However, current policy commitments to achieve this are deemed insufficient by the Office for Environmental Protection (OEP 2023). Therefore, further reaching policy will be needed and this leads to substantial transition costs in terms of higher costs for consumers (e.g. higher water, energy, bills) due to stringent environmental regulation and taxes passed on from service providers. Strong regulation on air quality hampers economic growth (e.g. increasing industry operating costs and private/public transport costs). Similarly, the current lag between government policy and net-zero goals results in accelerated action in the years leading up to 2030 with severe economy-wide interventions that also interact with growing physical risks from climate change. Movement away from carbon-intensive industries without a strong focus on a just and fair transition (e.g. reskilling and job opportunities), results in severe disruption to the labour force, increasing inequality and societal and geopolitical tensions (World Economic Forum 2022); IRENA 2022). Disagreements and political tension around net zero planning (McLaren and Corry, 2023), exacerbated by polarisation and misinformation in the media, further hamper coherent policy planning.

Rationale for likelihood: The UK government's recent relaxation of net zero policies increases the likelihood that 2030 targets will not be met (CCC 2023). Therefore transition risks are lower in the short-term, at the cost of greater physical risks down the line. A government re-orientation towards strong net zero policies, and/or change in sentiment as the physical risks of climate change become further apparent, may lead to an increase in the necessity for accelerated net zero and nature protection policies in the run up to 2050, at a time when they will also interact with worsening physical risks to drive economic and financial impacts. Rapid transition could lead to certain sectors suffering asset stranding. This is often considered in terms of fossil fuel producers in relation to climate policy, but major policy initiatives to drive food system transition towards lower environmental impacts could in theory lead to certain sectors (such as beef production) suffering from stranded assets, as well as significantly higher costs and market risks. As well as environmental restoration policy within the UK, transition risks could include policies to mitigate transboundary nature- related risks, for example diversifying import sources to improve food security, managing international refugee flows and dealing with AMR.

Rationale for impact: In a 2021 report on fiscal risks, the Office for Budget Responsibility estimated a net cost of the UK reaching net zero by 2050 to be £321bn, or just over £10bn per year (OBR, 2021). This is made up of around £1.4trn in costs, offset by around £1.1trn in savings. Delays in savings relative to costs potentially results in greater short-term drag on UK economic growth. Net zero targets cover more than two thirds of the global economy (Institute for Government, 2021). Transition to net zero drives financial risk in sectors and regions at different speeds, due to differences between policy, pricing power and carbon replacement costs, potentially resulting in supply-demand imbalance and rising inflation; an example being the energy and utilities sector post-pandemic (Power et al 2022). Where UK sectors are affected by additional net zero costs and firms operate in international markets (e.g. livestock production, electric vehicles) then there may be trade and competitiveness impacts. The UK cannot secure climate change mitigation alone; it makes up only around 1% of global emissions (albeit just under 5% of historical emissions) and there is a risk that other countries will not act in concert (Institute for Government, 2021).

OECD reviews suggest broad support for the existence of a 'pollution haven' effect, with imports of pollution- or energy- intensive goods increasing in response to tighter regulation (OECD, 2018). However, the effects tend to be small and concentrated in a few sectors. Overall, the effect of relative stringency on trade flows is overwhelmed by other determinants of trade such as skilled labour availability, access to raw materials, and transport costs (OECD, 2018). Policies to mitigate transboundary climate and nature-related risks are costly. For example, reducing biosecurity risks involves policy action on anti-microbial resistance. It is projected that AMR could cost from $300 billion to more than $1 trillion annually by 2050 worldwide (Dadgostar, 2019). Diversifying import sources to improve food security, and applying minimum sustainability criteria, could increase operating costs for retailers and lead to price rises. Dealing with increased refugee flows as a consequence of worsening global food security is likely to be a major cost for governments. Home Office documents suggest the increase in individuals illegally crossing the UK border is putting financial and economic pressures on UK Border Force, the UK asylum system, wider public sector spending, and local services' capacity and capability under existing processes (Home Office, 2023a).

Compounding threats (note, some are +ve associations, see rationales in table): Air pollution from wildfires; Biodiversity and mental health; **Deforestation; Direct damage from wildfires; Global food security repercussions; Flooding; Loss of pollinators; MBBF; North Sea fisheries;** Risks to tourism; Sitka spruce pest; Soil health decline; Zoonotic disease; **Livestock disease; Global food supply chain interruption from biodiversity-climate policy misalignment; Reputational risk, stranded assets and fund withdrawal; Housing asset risks; Corporate litigation; Government litigation.**

Risk title: 17) Antimicrobial resistance
One sentence risk description: Antimicrobial resistance affecting humans, animals/livestocks, and the environment
Risk type: Physical/Biological and health-related.
Risk source and timeframe: Domestic and transboundary, chronic (with acute disease epidemic events)
Plausible worst case scenario: 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 leads to more serious infections, longer hospital stays, higher medical costs, and higher mortality rates (WHO, 2023). Common procedures and treatments that rely on effective antimicrobials, such as surgery or chemotherapy, become riskier when antibiotic resistance is widespread. An increase in AMR-related mortality and morbidity puts a substantial pressure on the healthcare system (e.g., stretching hospital resources and costs). 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.

Rationale for likelihood: WHO declare AMR as one of the top 10 global public health threats facing humanity today; it impacts a range of actors (i.e., population, livestock, and environment) and sectors (e.g., health and food, affecting labour productivity/availability and macroeconomy more broadly). 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). 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. For AMR risks more generally, as of November 2023, 178 countries have developed AMR national action plans aligned with the Global Action Plan (WHO, 2023). These also include new multisectoral targets (Muscat, 2022), but of course effective implementation is key for reducing risk likelihood.

Rationale for impact: AMR is a significant global threat to human health causing increased mortality, more severe illness, and prolonged hospital stays. 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). Across the globe, 4.95 million (95% UI 3.62-6.57) deaths were associated with AMR, and 1.27 million (95% UI 0.911-1.71) deaths were directly attributable to AMR worldwide in 2019 (Murray et al. 2022). Official reports have estimated that about 10 million people will die across the world by 2050 if strong and effective action against AMR is not taken (Chokshi et al, 2019; Laxminarayan et al, 2013). Murray et al. (2022) estimated that 4.95 million (95% UI 3.62-6.57) deaths were associated with AMR, and 1.27 million (95% UI 0.911-1.71) deaths were directly attributable to AMR worldwide in 2019.

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, if there is no change in the current pattern of AMR, in ten years, the world working-age population will decrease by two years. This change will be more pronounced in Eurasia compared to the rest of the world (Taylor et al, 2014). To attempt to mitigate these impacts AMR will lead to increased public health expenditure. 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). High costs associated with expensive and intensive treatments and escalation in resource utilization are the direct monetary effects of AMR on health care (Prestinaci et al, 2015; Chokshi et al, 2019). Global trade will also be heavily affected by antimicrobial resistance if the continuous trends in AMR still persist (Lekagul et al, 2019). The World Bank report demonstrates that global exports might decrease significantly by 2050 due to the effects of antimicrobial resistance on labour-intensive sectors (World Bank, 2017). International travel could also become more restricted as infectious diseases become more difficult to control and contain. 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). AMR is projected to lead to decreased production and trade of livestock due to ineffective infection control, resulting 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). Antifungal resistance also poses a significant threat to food security (Fisher et al, 2018).

Compounding threats: Biodiversity loss and mental health impacts; **Freshwater pollution;** Global food security repercussions; Flooding due to deforestation and soil damage; Risks to tourism; ; Soil health decline; **Zoonotic disease; Livestock disease;** Global food supply chain interruption from biodiversity-climate policy misalignment; Business impacts due to UK-only biodiversity policies. Other factors: Global Trade and Travel. Theoretical arguments for AMR being exacerbated by different aspects of climate change, including extreme weather events, droughts, floods and increasing global temperatures (Burnham, 2021). Vector range and vector transmission are also expected to increase viral infection (Burnham, 2021). A correlative study suggests that climate warming is related to increased AMR transmission (Kaba et al, 2022). Nitrogen fertilization changes soil AMR gene profiles - although it is not clear that this increases or decreases resistance - one study concludes: "Therefore, as bacterial type and diversity change across soils, so too do their associated ARGs, resulting in resistomes that may respond to anthropogenic modulations (for example, nitrogen fertilizer) that do not possess obvious antibiotic-related properties" (Forsberg et al. 2014). Scoping review paper outlining arguments around honey bee health, AMR and links between climate change and environmental pollution (Kaba et al, 2022) - mainly suggesting research gaps, but highlighting some compounding threats with consequences for food security. See also Samreen et al. 2021 for general review of AMR and links to environment/nature including: "Non-antibiotic antimicrobial compounds (metals and biocides) prevalent in environmental samples are also responsible for the selection of resistance. Zinc-, copper-, mercury- and nickel-mediated selection of antimicrobial resistance genes (ARGs) has been well reported. The application of biocides, herbicides, pharmaceuticals and pesticides has also led to the selection of resistant micro-organisms, which pose serious challenges to the natural environment". There are strong arguments that biodiversity needs preserving in order to have the opportunity to develop drugs for the future. See e.g. Guardian 2021. Note also that diverse microbial communities can control the growth and spread of harmful bacteria by competing for resources and producing antimicrobial substances.

Risk title: 18) Aquaculture major pest or pathogen outbreak
One sentence risk description: Intensive aquaculture leads to outbreaks of pests which decimate productivity.
Risk type: Physical
Risk source and timeframe: Domestic and transboundary, chronic with acute phases
Plausible worst case scenario: Intensive fish farming encourages parasites and pathogens (such as algae and vibrio bacteria), which are exacerbated by warming waters under climate change. Pathogens novel to Scottish aquaculture arise or existing parasites become resistant to treatment (e.g. sea lice on salmon) leading to severe impacts on fish production and industry sustainability. Increasing frequency of extreme precipitation events and associated flooding are associated with significant nutrient pulses to the nearshore environment, which trigger harmful algae blooms.

Rationale for likelihood: Disease is a major risk for the current industry and is likely to remain so in the future (Gov. Office for Science, 2017), especially in light of aspirations to upscale bivalve seafood production (Willer, 2021). Novel pest/disease impacts may take several years to cause severe productivity loss allowing innovations to control them, including for example production of wrasse and lumpfish to remove sea lice from salmon. Some pests build up tolerance to chemicals used to control them, leading to additional industry costs. An increase in sea surface temperature and nutrient runoff may promote the establishment of new harmful algal species in UK waters and alter algal toxicity, which can can adversely impact shellfish productivity (Brown et al, 2022) (though note also that gradually increasing nutrients may also have benefits for shellfish species from increasing food availability; MCCIP, 2011).

Rationale for impact: In 2018, the UK produced 0.9 million tonnes of fish (including molluscs and crustaceans), with a value of £2.2 bn, 50% of which comes from aquaculture (and 50% from capture of wild fish; OECD 2021). Scotland's aquaculture broader supply chain includes upstream businesses supplying farms with inputs such as feed and equipment, and downstream processing and handling businesses, including the retail and food service sectors. Impacts across the supply chain have been estimated to be around £620M in GVA and 12,000 jobs across the Scottish economy. The sector is dominated by Atlantic salmon farming (97% in 2018) (Marine Scotland, 2020) with other aquaculture species including Rainbow trout (freshwater production) and Blue mussels with a niche industry of seaweed. The UK fish and seafood market is currently dominated by imports (43 per cent) and capture fisheries (40 per cent) with aquaculture making up only 17 per cent of domestic supply (Gov. Office for Science, 2017). This means fish supply for retail and restaurants would likely adapt by alternative supply chains, but salmon exports could be strongly impacted. Scottish exports of all fish and seafood were valued at £1.04 billion in 2022 with Scottish salmon the UK's biggest single food export from HMRC data (Salmon Scotland, 2023).

Compounding threats: Algal blooms; Deforestation; North sea fisheries; Ocean acidification; Livestock disease; Global food supply chain interruption from biodiversity-climate policy misalignment; Business impacts due to UK-only biodiversity policies; Reputational risk, stranded assets and fund withdrawal. Other factors: genetic/fitness degradation of salmon populations; ocean warming; ocean acidification. Energy costs have a high impact on the development of UK aquaculture, affecting feed, transportation, infrastructure and fabrication costs (Gov. Office for Science, 2017). Extreme weather arising from climate change is likely to have significant impacts on fish, mussel and oyster production in the sea. Most of UK aquaculture production is vulnerable to storm events. Structural damage to farm infrastructure is the main risk and may cause fish escapes or mortality. The value of lost stock in Scotland has been estimated as about £1.5 million for 2009 (Jackson et al. 2015).

Risk title: 19) Business impacts due to UK-only biodiversity policies
One sentence risk description: Reduced competitiveness of UK industry due to biodiversity policies implemented in the UK only
Risk type: Transition
Risk source and timeframe: Domestic and transboundary, chronic
Plausible worst case scenario: UK implements biodiversity frameworks more rapidly than other countries and is impacted as a result (Environmental Improvement Plan, 2023). Where UK sectors affected by additional biodiversity protection costs operate in international markets (e.g. livestock production, fish exports) there are trade and competitiveness impacts. Severe industry impacts could lead to certain sectors suffering asset-stranding. This is often considered in terms of fossil fuel producers in relation to climate policy, but major policy initiatives to drive food system transition towards lower environmental impacts could in theory lead to certain sectors (such as beef production) suffering from stranded assets, as well as significantly higher costs and market risks.

Rationale for likelihood: OECD evidence reviews suggest broad support for the existence of 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. Overall, the effect of relative stringency on trade flows is overwhelmed by other determinants of trade such as skilled labour availability, access to raw materials, and transport costs (OECD 2018). Brexit has increased the potential for divergent environmental policies to emerge, both between the UK and the EU and between the devolved administrations of Northern Ireland, Wales and Scotland. Significant divergence between UK and EU policy design and implementation is already apparent, and this has resulted in growing administrative costs for companies trading in both jurisdictions (Smith et al. 2022). The area of environmental product standards is particularly economically sensitive due to the increased costs and delays associated with border checks (Baldock and Nicholson 2022). The UK government's recent relaxation of net zero policies suggests further divergence with EU environmental policy is likely to take the form of deregulation rather than tighter regulation. However, a re-orientation to strong environmental policy aiming to deliver the biodiversity objectives in the UK 25 Environment Plan and the Kunming-Montreal Global Biodiversity Framework (CBD, 2023), could lead to wider economic impacts. For example, a weak interpretation of the '30 x 30' target leads to delineation of protected areas (many of which already exist, such as SSSIs), but a strong interpretation requires shifting protected areas to favourable conditions (BES, 2022). This requires wider landscape restoration to reduce habitat fragmentation, reduce harmful agricultural practices and atmospheric nitrogen inputs, which would be a major socioeconomic transformation.

Rationale for impact: There are arguments that the economic benefits of addressing biodiversity loss outweigh costs (Sumaila et al. 2017), but that may not be the case when biodiversity policies are misaligned globally. Currently, most countries have failed on Convention for Biodiversity targets (CBD 2020). In 2020/2021, £624 million of UK public sector funding was allocated to biodiversity in the UK equating to 0.023% of UK GDP (JNCC Indicator E2, 2023). Costs to reverse genuine biodiversity loss would be substantial. To reverse the decline in biodiversity by 2030, analysis suggests that, globally, it would cost between US$ 722-967 billion each year over the next ten years. This puts the biodiversity financing gap at an average US$ 711 billion or between US$ 598-824 billion per year (Paulson Institute, 2023). Reversing biodiversity loss also requires halting harmful subsidies, the major part of which come from agricultural subsidies. The re-organisation of agri-environment scheme funding in the UK (i.e. the new ELMS scheme) is ongoing, and could lead to increased food production costs and export competitiveness. Effects are likely to vary across and within asset classes; eg. whilst exports of some crops such as wheat and barley are projected to decline as a result of the implementation of biodiversity policies, others such as rapeseed and pulses are projected to increase (Smith et al. 2022). Strength and breadth of biodiversity implementation may depend on social opinion (influenced by media and potentially by misinformation) and cross-party political consensus.

Compounding threats: Algal blooms in water ecosystems; AMR; Biodiversity loss and mental health; Deforestation; Freshwater pollution; **Grain crops pest / pathogens;** Global food security repercussions; **Loss of pollinators;** Multiple breadbasket failure; North sea fishery collapse; Ocean acidification; Risks to tourism from nature damage; Scottish aquaculture major pest outbreak; **Soil health decline;** Zoonotic disease; **Livestock disease; Corporate litigation.**

Risk title: 20) Corporate litigation cases
One sentence risk description: Environmental damage prompts legal action against corporations
Risk type: Litigation
Risk source and timeframe: Domestic and transboundary, chronic with acute phases
Plausible worst case scenario: Corporate litigation cases on nature continue to rise across several fronts and jurisdictions. These include: action from conservations NGOs to protect species from activities which put them or their habitats at risk (Climate Change Litigation Database, 2018a), investment in and financing of activities which have detrimental environmental impacts (Climate Change Litigation Database, 2023), deforestation activities in protected areas (Climate Change Litigation Database, 2010), ecosystem and climate damage in concession areas (Climate Change Litigation Database, 2019) and increase exposure from the lack of a divestment from fossil fuel investments strategy (Climate Change Litigation Database 2018b). Litigation cases rise as physical risks through biodiversity loss as well as climate change impacts worsen (CFRF, 2022; NGFS 2021). Given multinational corporations' presence in several countries, corporate reputation is negatively affected regardless of the country where litigation is initiated. This, in turn, has negative economic impacts on corporation results (Sato et al 2023) which have a range of impacts in different locations, and also leads to increased exposures for the insurance sector (CFRF, 2022).
Rationale for likelihood: Corporate litigation cases for environmental damage are increasing in frequency both globally and in the UK. Examples include: in 2018, the Federal Court of Australia restraining a forestry company from conducting operations given that the Greater Glider Species, a threatened species, were heavily reliant on the trees (Climate Change Litigation Database, 2018a); in 2022, BNP Paribas was sued in France by a Brazilian NGO claiming the bank finances companies which contribute to deforestation in the Amazon (Climate Change Litigation Database, 2023); in 2010, a Court of Justice in Brazil convicted the CEO of a company for deforestation of a protected area as a result of cattle-raising activities (Climate Change Litigation Database, 2010); in 2019 and 2021, a District Court in Indonesia ruled for the Ministry of Environment and Forestry against a corporation for damages and restoration costs of peatlands which were drained to clear land for palm plantations (Climate Change Litigation Database, 2019; Climate Change Litigation Database 2018b), and in 2021, academics and contributors to the University Superannuation Scheme sued the University Superannuation Scheme Limited (USSL) in the UK High Court

for the lack of a clear divestment plan from fossil fuel investments (Climate Change Litigation Database 2021). Climate litigation started in the 1980s and increased steeply recently, with more than 25% cases in the last three years (CFRF, 2022).

Rationale for impact: Litigation against corporations has direct impacts in fines and a negative effect on their reputation, which translates into negative economic impacts. For example, a recent study showed a climate litigation case can decrease a firm's value by 0.41% (Sato et al, 2023). These impacts can cascade to the financial system and increase loan defaults. In contrast, an increase in adherence to environmental regulation can result in price shocks over different supply chains (e.g. palm oil prices rises due to an increase in peatland protection and restoration in Indonesia). In addition, it may be possible for corporations to end operations in certain countries with a higher litigation rate.

Compounding threats: Deforestation; Wildfires; Freshwater pollution; Flooding; Risks to tourism; Soil health decline; **Net zero policies; Global food supply chain interruption from biodiversity-climate policy misalignment;** Business impacts due to UK-only biodiversity policies; **Reputational risk; Housing asset risks, Government litigation.** Other factors: Climate change litigation cases which corporations may simultaneously face.

Risk title: 21) Government litigation cases
One sentence risk description: Failure to comply with environmental legislation prompts legal action against UK government
Risk type: Government litigation
Risk source and timeframe: Domestic and transboundary, chronic
Plausible worst case scenario: Litigation cases against the government to meet the commitments set in the Environment Act (Gov.uk, 2021) negatively affect the UK's reputation as a global leader in green finance (Gov.uk, 2023) and also affect investor confidence. The increase in litigation cases vs. government follows from precedent on government litigation cases in the UK related to failure to meet the Climate Change Act (ClientEarth, 2023; Climate Change Litigation Database 2022a; Climate Change Litigation Database 2022b; Climate Change Litigation Database 2021a; Climate Change Litigation Database 2020a; Climate Change Litigation Database 2017; Climate Change Litigation Database 2009), misalignment with the Paris Agreement (Climate Change Litigation Database 2021b; Climate Change Litigation Database 2020b), unlawful disclosure of climate-risks (Climate Change Litigation Database 2023) as well as an increase in climate litigation cases globally (CFRF 2022). Litigation cases are expected to rise as physical risks through biodiversity as well as climate change increase (CFRF 2022; NGFS 2021).

Rationale for likelihood: In 2021, the UK Environment Act was passed as a law including ambitious long-term targets on biodiversity, water, clean air and waste and recycling as well as establishment of due diligence systems for supply chains' regulated commodities and companies (Gov.uk, 2021). Litigation cases against the UK Government on breaches to the UK's climate change Act (2008) and its 2019 target amendments include: the net zero strategy (ClientEarth, 2023; Climate Change Litigation Database 2022b); the "Jet zero" strategy to decarbonise the aviation sector (Climate Change Litigation Database 2022a); oil & gas strategy (Climate Change Litigation Database 2021a); energy policy statements (Climate Change Litigation Database 2020a) and failure to readjust the 2050 emissions reduction targets to achieve 1.5 °C global temperature increase as (Climate Change Litigation Database 2017). Litigation cases against the UK Government on the grounds of misalignment with the Paris Agreement include action against "supporting coal and aviation, granting oil and gas leases, investing more than 25 billion pounds in roads, and financing fossil fuel projects overseas" (Climate Change Litigation Database 2021b) and the "Second roads investment strategy" (Climate Change Litigation Database 2020b). Climate litigation started in the 1980s and increased steeply recently, with more than 25% cases in the last three years (CFRF 2022). According to a survey by NGFS, 58% respondents estimate climate change litigation will increase (NGFS 2021).

Rationale for impact: As with the increasing trends in climate litigation, increases in other nature-related litigation against governments impact on different stakeholders which operate in each country: policymakers, legislators and parliamentarians, companies, investors and private citizens. While part of the European Union the UK government was successfully sued by Client Earth in 2016 for failure to tackle illegal air pollution across the UK (Client Earth, 2016) and then by the European Court of Justice for "systematically and persistently" breaching air pollution limits" since 2010. Costs could run into millions of pounds, but it is not clear legally whether the UK could be forced to pay, following Brexit (BBC News, 2021). In any future cases where the government has breached legal limits, the case would be dealt with by a new UK Office for Environmental Protection (OEP). The OEP legally created in 2021 has functions in England and Northern Ireland to hold the government and other public authorities to account against their environmental commitments and compliance with environmental law (Office for Environmental Protection, 2023). Its effectiveness remains to be demonstrated, but other non-government actors are still active in pursuing legal failings by the UK government. For example, ClientEarth, Friends of the Earth and the Good Law project sued the government over their net zero strategy (Client Earth, 2022). The OEP is also active in intervening in legal cases such as a 2022 case on Environmental Impact Assessment (OEP, 2022). The UK global leadership in green finance also increases its accountability globally (Gov.uk, 2023).

Compounding threats: Deforestation; Wildfires; Freshwater pollution; Global food security repercussions; Flooding; Loss of pollinators; North Sea fisheries; Ocean acidification; Risks to tourism; **Net zero policies; Global food supply chain interruption from biodiversity-climate policy misalignment; Reputational risk; Housing asset risks; Corporate litigation.** Other factors: Climate change litigation cases which further exacerbate the legal burden, financial costs and reputational costs faced by a UK government.

Risk title: 22) Grain crops pest / pathogen outbreak
One sentence risk description: Large cereal monocultures are susceptible to novel crop pest and disease outbreaks
Risk type: Physical
Risk source and timeframe: Domestic and transboundary, acute
Plausible worst case scenario: This scenario explores the implications of an acute shock of multiple cereal pest outbreaks that will affect the UK cereal industry and related industries. Warmer atmospheric and soil conditions provide a hotbed for crop disease relating to cereal crops which will increase the risk of crop failure and loss of biodiversity. A decline in topsoil thickness, soil water content (and other water stores) and fertility, and repeated widespread crop pest outbreaks will ultimately lead to the loss of the East Anglian (and surrounding area) food basket. Once this boundary has been crossed, a permanent tipping point will be unavoidable and irreversible, leading to serious socio-economic implications relating to the UK food sector and the health of the UK population.

Rationale for likelihood: The increasingly warmer atmospheric and soil conditions increase the incidence of cereal crop diseases. Note that some diseases, e.g., wheat brown rust, thrive during hot humid weather, especially in April to July (AHDB, Brown rust). In the UK, thunderstorms are often associated with the end of a hot spell. Hence, diseases such as brown rust in wheat may also become more prevalent. In the UK, severe outbreaks of stem rust are extremely rare. The pathogen has a complex life cycle, which depends on the presence of hosts (wheat and barberry) and favourable conditions – the optimum temperature is above 20°C) and suitable air movement. Unfortunately, environmental conditions have become more conducive to support stem rust infection over the past 25 years (in 2013, stem rust was recorded in UK crops for the first time in over 60 years; see AHDB, 2023a). In Britain, airborne urediniospores generally originate from South West Europe and North Africa (AHDB, 2023b). These spores, when air movements are appropriate, cause initial infection on wheat. With disease on the rise in these regions, and with atmospheric flows changing there is potential for this disease to become more important in the future. However, novel disease impacts are unlikely to emerge very rapidly (i.e. may take several years to cause very significant yield loss). Not all countries are likely to be affected, meaning that the food and financial system can adapt by alternative supply chains.

Rationale for impact: The UK is largely self-sufficient in production of grains, producing over 90% of wheat, and 100% of barley and oats (Defra, 2023d). Currently 81% of wheat milled in the UK is home-grown, with the remainder imported from Canada (10%), Germany (9%), and France (1%) (UK Flour Millers - Statistics). This means that the UK has a lower dependency on wheat that is grown in countries affected by adverse geopolitical conditions (e.g., the Ukraine currently). The milled wheat is used by bakeries (65%), for biscuits and cakes (13%), household flour (5%) while the rest is exported (UK Flour Millers - Statistics). A large proportion of the malting barley grown in the UK is used to make malt for domestic brewing and distilling, with malting barley varieties estimated to make up around 60% of barley area (AHDB, 2022). If major yield losses did occur then a high proportion of small farms might default on loans, which could cause exposure to particular financial institutions. Furthermore, a lack of domestic wheat and barley supply will affect the baking and beer-making industries. If wheat production elsewhere is also affected, e.g. due to geopolitical factors, then the financial impact could be significant.

Compounding threats: Air pollution from wildfires; **Global food security repercussions;** Loss of pollinators; **MBBF;** Sitka spruce pest; Soil health decline; **Global food supply chain interruption from biodiversity-climate policy misalignment; Business impacts due to UK-only biodiversity policies;** Other factors: Extreme weather (drought, intense rainfall, heatwave) can exacerbate crop failures and potential efficacy of crop protection chemicals (Boxall et al., 2008). The cascade of events related to extreme weather events will have detrimental direct and indirect effects on the production part of the UK food supply chain, as well as other parts of the chain. For example, the hot and dry environmental conditions will increase the risks of wildfires in the area, with implications for storage & processing, distribution and retail (e.g., via high temperatures impacting transport through road melt, rail buckling and smoke, danger to life, or loss of assets; Falloon et al, 2022). The lack of water in the area will also negatively impact various processing entry points, as water is a prime component in the various processing procedures (e.g., beer production). Heatwaves will also affect the availability of staff for crop harvesting, food processing (e.g., flour milling for bread and cakes, malting for beer), transport of raw and processed foodstuffs, and retail activities. Biodiversity loss / ecosystem simplification is expected to increase emergence of plant viruses although limited evidence (Roossinck and Garcia-Arenal, 2015), though other papers discuss how architecture of agroecosystems makes rapid emergence of pathogens possible (McDonald and Stukenbrock, 2016). An IPBES report states that globally, local varieties and breeds of domesticated plants and animals are disappearing (Brondizio et al, 2019). This loss of diversity, including genetic diversity, poses a serious risk to global food security by undermining the resilience of many agricultural systems to threats such as pests, pathogens and climate change.

Risk title: 23) Livestock disease
One sentence risk description: An animal-borne disease caused substantial impacts to the livestock or poultry industry
Risk type: Physical
Risk source and timeframe: Domestic and transboundary, acute
Plausible worst case scenario: An animal-borne pathogen (e.g, avian influenza or H1N1 swine flu) becomes widespread meaning severe control measures are needed, leading to widespread culling and collapse of the industry (HMG, 2023). Public confidence is impacted and consumer choices shift away from affected meat types. Companies face massively reduced sales and struggle to raise credit due to high market risk, leading to collapse of SME and agribusinesses. Firesales of livestock-related assets cause further financial instability.

Rationale for likelihood: There are historic cases of diseases that have been controlled to date (at substantial cost, e.g. foot and mouth in cattle, avian influenza, bovine TB) but also high potential for exotic diseases to gain a foothold in the UK; for example, brucellosis, Rift valley fever and Crimean-Congo haemorrhagic fever (Public Health England, 2023). Climate change could increase risks through intensive indoor-rearing to reduce GHG emissions and energy costs, and also through weather conditions that favour mosquito vectors (e.g. West Nile virus). Furthermore, livestock and zoonotic disease emergence is increased by greater human-wildlife interaction as a result of global deforestation for cattle ranching (IPBES 2020). Global meat consumption over the next decade is projected to increase by 14% by 2030 driven largely by income and population growth (OECD-FAO, 2021), and this increased production may lead to greater risks from livestock disease transmission. Globalised markets and high international connectivity allowing pathogen transmission also mean that novel strains or new diseases may have a rapid and widespread impact.

Rationale for impact: In 2022, agriculture's contribution to the UK economy (Gross Value Added at basic prices) was £13.9 billion (0.6% of GDP) (Defra, 2023e). Livestock is 54.3% of the total economic activity in UK agricultural production. Total value UK exports which are livestock related (2022 values) is £6.9 bn, comprising £2.8 bn dairy and eggs, £2.1 bn meat and meat preparations, £1.2 bn animal feeding stuffs, £751M live animals (ONS, 2023b), representing 1.67% of total UK goods exports. 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). Foot and Mouth disease in 2000 cost the UK £25–30 billion through slaughter of cattle, loss of jobs and markets (FAO, 2004). BSE in the 1990s cost the EU €92 billion long-term cost (Cunningham, 2003) (FAO, 2009).

Compounding threats: Algal blooms; AMR; Biodiversity and mental health; **Deforestation; Freshwater pollution;** Global food security repercussions; **MBBF; North Sea fisheries;** Risks to tourism; **Aquaculture pest; Zoonotic disease; Net zero policies; Global food supply chain interruption from biodiversity-climate policy misalignment; Business impacts due to UK-only biodiversity policies.** Other factors: International trade drives zoonotic disease spread and also is affected by outbreaks; for example, through sanitation measures (infected animal destruction, quarantine, trade embargoes) causing significant disruption to supply chains.

Risk title: 24) Loss of pollination service
One sentence risk description: Loss of pollinating insects in the UK affects topfruit productivity (e.g. apples) as well as other pollinator-dependent crops such as strawberries and field beans.
Risk type: Physical
Risk source and timeframe: Domestic and transboundary, chronic
Plausible worst case scenario: A continued loss of bees, hoverflies and Diptera due to ongoing habitat loss, pesticides and climate change mean that topfruit and other pollinator-dependent agriculture suffers severe pollination deficit leading to major yield reductions and reduced fruit quality. Crop declines could be further exacerbated by concurrent losses in moths, that may contribute more to crop pollination than previously thought (Macgregor et al 2018).

Rationale for likelihood: Pollinators losses have been occurring gradually in the UK over decades (Powney et al 2019), with subsequent pollination deficits, e.g. in apple orchards (Garratt et al, 2021). There is no clear evidence that rapid tipping points will occur, although there is evidence for rapid change between years in some instances (Powney et al 2019). There is relatively high redundancy (e.g. multiple pollinator species per crop) (see e.g. Ghazoul 2005; Hutchinson et al. 2021) meaning reasonable resilience to pollinator species loss, although it is unclear to what extent there is redundancy in how pollinator species respond to additional environmental changes. However, a few wild pollinating species provide the majority of crop pollination services for fruit and vegetable species (Kleijn et al 2015), suggesting that loss of these pollinator species, if not replaced, could be damaging. The conclusions of Kleijn et al 2015 were based on global datasets, with the majority of data from outside of the UK; UK crops included apples, oil seed rape, field bean and strawberry. However Kleijn et al 2015 also demonstrated that these few pollinator species typically do well in agricultural landscapes, and respond positively to agri-environment measures such as buffer strips and wildflower meadows, also found to be the case for the UK (Redhead et al, 2018; Image, et al 2022). Overall, we therefore consider there to be a low likelihood that a rapid loss of pollinator services will happen across the UK though localised instances could occur. Losses in pollinators in certain countries will likely lead to shifts in value of global pollinated crop production towards other countries (Murphy et al 2022), though losses in these countries (i.e. global pollination crisis) would lead to major food insecurity (IPBES, 2016).

Rationale for impact: Value of UK-produced fruit and vegetables in 2022 was £1.0BN and £1.78BN respectively (Defra, 2022c), though insect pollinators benefit the yield and/or quality of only 37% of UK food crop species (LWEC, 2014). Pollination services in the UK are thought to increase productivity by ~£630 M per year based on an average of 2014–2016 data (Breeze et al, 2020). Businesses growing fruit and vegetables employ over 50,000 people in the UK (UK Parliament, 2022b). Under major yield losses a number of agricultural/horticultural firms could default on loans which could cause particular financial institutions to be exposed. However, pollinator loss is a chronic issue and there is some opportunity for business adaptation. In polytunnels, robotic-pollinating drones have been used, though there are severe technical, financial and environmental limitations to their widespread applicability (Potts et al, 2018). Hand pollination is also used in global commercial crop production and can strengthen the resilience of farm systems responding to pollination limitations, though it also increases labour costs (Wurz et al. 2021) making it prohibitively expensive and also not viable for some crops. At the national level pollinator decline is a risk to food security (although pollinator-dependent crops provide less calories than cereal crops, they provide essential micronutrients supporting health; Smith et al, 2015). Opportunities for future crops, such as soy and sunflower could be limited by pollination service losses. Domestic declines in pollinator-dependent crop yields could, in theory, be offset from increased imports (currently 61% UK food self sufficiency; UK Parliament 2020), but global social and environmental challenges could threaten this supply. Similarly, implementation of Pollination Action Plan (HMG, 2022) principles could reduce domestic crop yield impacts.

Compounding threats: Biodiversity loss and mental health; **Deforestation; Wildfires;** Grain crops pest/pathogen, **Global food security repercussions, MBBF;** Sitka spruce pest; **Soil health decline; Net zero policies; Global food supply chain interruption from biodiversity-climate policy misalignment; Business impacts due to UK-only biodiversity policies;** Reputational risk, stranded assets and fund withdrawal; **Government litigation.** Other factors: Extreme weather (drought, false springs affecting insect phenology, warm winters increasing pathogen risk to insects) (see also Settle et al 2016; Gérard et al 2020). Diversity in pollinating communities is important to buffer against environmental changes, as demonstrated in almond orchards in America, in response to changing wind speed (Brittain et al 2012).

Risk title: 25) North sea fishery collapse
One sentence risk description: Collapse of fish stocks in UK fisheries
Risk type: Physical
Risk source and timeframe: Domestic and transboundary, acute
Plausible worst case scenario: Impacts of overfishing combine with pathogens exacerbated by climate change and a shifting geographic distribution of fish stocks due to ocean warming. As a consequence, UK fisheries experience a collapse of fish stocks with implications for fishing industry defaults on loans.

Rationale for likelihood: In 2000, 56% of UK quota-fish stocks were fished sustainably, at or below acceptable mortality range levels, 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). It has been a challenge, complicated by Brexit, to manage the stability of stocks of over 100 fish species over the region between EU, Norway and the UK, resulting in collective overfishing for some commercial stocks (ICES). Studies have also shown that climate change also plays a large role in stock distribution, survival rates and therefore abundance, particularly for commercially important species such as cod (Copernicus, 2019). Projections indicate failure to manage fishing and climate-induced environmental change would lead to a shock that could result in a collapse in the North Sea fishery (Beaugrand 2022). For example, the cod fishery in the North Sea has already been struggling with continued decline in numbers despite an implemented recovery plan (Copernicus, 2019). Past fishery collapses, such as the collapse of the Newfoundland fishery as well as haddock and flatfish, has shown that recovery is incredibly difficult, particularly with the additional challenge of climate change (Beaugrand 2022). In addition, there is evidence that an increase in ocean temperature is likely to cause an increase in the marine bacteria, such as of the genus Vibrio, which will increase their associated diseases (Vezzulli et al, 2012).

Rationale for impact: Overall, since 1984 UK has been a net importer of fish from the North Sea (House of Commons 2022). ONS estimated that in 2021 the industry contributed 0.3% of UK total economic output and 5% of overall agriculture, forestry and fishery sector (House of Commons 2022). In 2021 the UK imported 655 thousand tonnes of sea fish, with a value of £3.1 billion and exported 350 thousand tonnes, with a value of £1.6 billion, leaving a crude trade gap of 305 thousand tonnes (House of Commons 2022). Norway was the largest exporter of fish into the UK at 15.1% of imports and France was the largest importer of UK-based fish at 46.3% (House of Commons 2022). Therefore, a collapse of the fishery would impact the UK's exportation but also its importation of fish products as Norway also relies on the North Sea fishery. Fisheries in the UK employ 10,724 people across primarily Scotland and England - with the equivalent of approximately 6,835 full-time equivalent jobs when accounting for hours worked (House of Commons 2022). There is a general trend in decreasing employment in the fishery industry as well as in the number of vessels in the UK fishing fleet (House of Commons 2022).

Compounding threats: Algal blooms; Biodiversity and mental health; **Deforestation; Global food security repercussions; MBBF;** Ocean acidification; **Aquaculture pest outbreak; Livestock disease; Net zero policies; Global food supply chain interruption from biodiversity-climate policy misalignment;** Business impacts due to UK-only biodiversity policies; Reputational risk; **Government litigation.** Other factors: Ocean warming, geopolitical factors, ocean acidification, shifting industry and consumer demand away from meat and towards fish for environmental and health related reasons, success or failure of the aquaculture industry to fully substitute fishmeal and fish oil in aquafeeds for alternatives.

Risk title: 26) Reputational risk, stranded assets and fund withdrawal
One sentence risk description: Low confidence in management of environmental risks and/or stranded assets leads to mass withdrawal from retail banks.
Risk type: Transition
Risk source and timeframe: Domestic and transboundary, chronic
Plausible worst case scenario: Low confidence in banks' management of environmental risks and/or stranded assets leads to mass withdrawal from retail banks, bank default and potentially contagion effects across the financial system. Low confidence stems from lack of management of physical risk to assets relating to nature dependence and degradation or lack of management of transition risk due to introduced policies impacting investments.

Rationale for likelihood: With the rise of mandatory disclosures for nature-related risks (e.g. see TNFD recommendations), there could feasibly be a requirement for banks to disclose against their nature-related impacts and dependencies, providing consumers with more information on risk exposure and requiring greater risk management practices. Reputational risk leading to lower confidence could stem from perceived poor management of physical or transition risk. On the physical risk side, if there is a major collapse of an ecosystem service which banks are heavily exposed to based on their lending or investment portfolio, there could be reputational damage to the bank either through media coverage, activist movements or watchdog coverage. This may spiral into market risks associated with certain asset classes and stranded assets. Similarly with exposure to nature-related transition risk - if biodiversity net gain or other nature-related policies/commitments are to be implemented in the next 5-10 years, banks without sufficient plans to decrease their exposure to changing asset prices might face increased reputation damage and risk (DEFRA 2023f; NGFS 2022). Research suggests that businesses with a high environmental impact are at risk of reputational damage, resulting in boycotts or protest (Blackrock, 2022). This could lead to lower confidence and the removal of bank deposits. Additionally, a disorderly nature-related transition could open banks to high levels of transition and physical risk as degradation would continue to occur in jurisdictions with weak action while assets have higher risk of price drops in areas with strong action.

Rationale for impact: In the event of a depository redistribution, it is possible that the government might have to bail out the bank to prevent wider potential impacts of the rest of the financial system. Furthermore, depending on the trigger event, there could be a contagion effect where several banks are impacted by depository redistribution, causing greater system-wide risk to the financial sector. During the 2007-2009 financial crisis, The UK Government had to step in and inject £137 billion of public money to stabilise the financial sector (Bank of England, 2021). A run on the UK's fourth biggest bank, Northern Rock, in late 2007 shows how perceptions of deposits at risk can quickly lead to depository redistribution and bank collapse (or bail out and nationalisation; BBC News 2017). If the trigger event was due to a wider lack of trust in the management of banks or central bank supervision of environmental risks or a major ecosystem service collapse, there could be higher risks of contagion. Alternatively, if the trigger was related to the reputational damage faced by a single bank, there might be a faster withdrawal from one bank requiring intervention but less likelihood of a contagion event.

Compounding threats: Deforestation; Flooding, Loss of pollinators; MBBF; North Sea fisheries; Aquaculture pest outbreak; **Net zero policies; Housing asset risks; Corporate litigation; Government litigation.** Other factors: Ecosystem service collapse, disorderly transition/quick and large policy change, mandatory disclosure (regulatory change)

Risk title: 27) Sitka spruce pest outbreak
One sentence risk description: Monoculture plantations of sitka spruce are decimated by a major pest or disease outbreak.
Risk type: Physical
Risk source and timeframe: Domestic and transboundary, acute
Plausible worst case scenario: A novel pest or disease spreads rapidly through sitka spruce plantations, the UK's primary forestry product, leading to major timber yield losses and impacts on forestry industry.
Rationale for likelihood: Sitka spruce Picea sitchensis is currently one of the most widely planted timber forest trees in the UK. Pests such as the spruce bark beetle Dendroctonus micans are now established in the UK, along with green spruce aphid (Forestry Commission 2018). Other pests such as European spruce bark beetle Ips typographus are not established but likely to do so. The beetle, in association with pathogenic fungi (particularly the blue stain fungus Endoconidiophora polonica), has the potential to cause significant damage to Britain's spruce-based forestry and timber industries (Forest Research 2023a). Sitka spruce trees grow best in moist soils in areas with >1000mm rainfall per year (Forest Research 2023a), so, under climate change, the performance of the species declines leading to susceptibility to large pest outbreaks that cause major loss of timber crop over several years. The likelihood of a pest outbreak is greater in monocultural plantations, as compared to more diverse stands, due to them being more susceptible to pest outbreaks due to a variety of underlying mechanisms (as demonstrated across timber species; Jactel et al 2021). This has led to calls for more diverse forest plantations in the future, if planting / management / harvesting practicalities can be overcome and planting suitably incentivised (Messier et al 2021). Adoption of these recommendations would likely lower the risk of pest outbreaks.

Rationale for impact: UK industry use of wood (sawn, panels, pellets, pulp and paper) is dominated by imported wood. According to provisional figures for 2022 (Forest Research 2023b), just under half of sawn wood products were from UK-sourced wood as compared to imported wood, while other uses were dominated by imports e.g. (£11.5 billion value in 2022, versus £2.25billion produced in UK for export). Hence, UK firms are less vulnerable to domestic pest impacts, and depend more on the diversity and resilience of imported supply, though this could change in future with changes to sustainability standards or import/export regulations.

Impacts of domestic pests affect timber yields gradually over c.4 decades based on average harvest times and heterogeneity in stand age. Hence, the industry and financial system likely have time to adapt to risks.

Compounding threats: Air pollution from wildfires; Biodiversity and mental health; **Deforestation; Wildfires;** Grain crops pest/pathogen; **Flooding;** Loss of pollinators; Risks to tourism; **Soil health decline;** Net zero policies. Other factors: Monoculture makes plantations more susceptible to pest outbreak (as well as other threats). Diversity in habitats in surrounding landscape may allow persistence of beneficial natural enemies (that suppress pests) even if stands remain monocultural. Other compounding factors include drought, late spring frost, trade in nursery stock (quality of plant passports), soil health (moisture), wildfires, air pollution - essentially any factor that makes spruce more susceptible to pests. Note, the concept of Manion's tree decline spiral that pest outbreak is 'final nail in the coffin' whereas there are predisposing and inciting factors (e.g. soil type and drought respectively) that make species more susceptible to contributing factors to death, such as pest outbreaks (Verheyen 2021). This was also seen in the mass die-off of spruce (and other important temperate forest species in Central Europe) following drought in 2018 across Europe, particularly evident in sites of suboptimal condition (Schuldt et al, 2020). Trade is a key factor, whereby increases in global trade of living plants, harvested products and related materials (contaminated soil) drive the emergence and transmission of novel pests and pathogens (e.g. of particular concern are multi-species pathogens such as the Phytophthoras).

Risk title: 28) Soil health decline
One sentence risk description: The loss of top soil through erosion and loss of soil biodiversity through heavy chemical inputs severely compromises crop yields and carbon storage.
Risk type: Physical
Risk source and timeframe: Domestic and transboundary, chronic
Plausible worst case scenario: Gradual loss of top soil layer thickness and/or quality (due to compaction, water and wind erosion, biodiversity loss, land loss of nutrients) occurs leading to reduced yields, particularly of crops in highly productive East Anglia regions of UK, and in some regions from which we rely on imports. The overall drier conditions in East Anglia, and lack of crop cover as a result of stunted or failed crops, lead to soil removal via windstorms, comparable to the dustbowl in America in the 1930s. The occurrence of increasingly 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 is washed away into streams, with further implications for water quality. Rising temperatures will cause accelerated breakdown of soil organic matter, which has 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. Price rises of chemical fertiliser also exacerbate impacts leading to marked price increases of cereals on the world market.

Rationale for likelihood: Almost 4 million hectares of soil in England and Wales are at risk of compaction, and 2 million hectares of soil are at risk of erosion (Environment Agency, 2023). Every year England and Wales loses 2.9 million tonnes of topsoil to erosion. National Soil Inventory analysis for England and Wales found that between 1978 to 2003 carbon was lost from soils across England and Wales at a mean rate of 0.6% yr(-1) (relative to the existing soil carbon content; Bellamy et al, 2005). Spreading of some contaminants onto soils is poorly controlled and some 300,000 hectares are contaminated in the UK

(Environment Agency, 2023). Sewage sludge can contain materials such as metals, microplastics, persistent organic pollutants and pharmaceuticals which contaminate the soil (FAO, 2021). Changes to the types of crops grown can alter risks to soil health, for example intensive maize is particularly harmful to soils and production has tripled since the early 1990s (partly for biofuel production; Soil Association, 2015), whilst overwinter cover crops may reduce soil loss. Climate change interacts with soil health with more intense rainfall events worsening soil erosion.

Rationale for impact: Soil degradation (calculated in 2010) is thought to cost £1.2 billion every year (Environment Agency, 2023). One third of the UK wheat crop is grown on drought-prone soils, resulting, on average, in a 10 to 20% loss in total production, valued at £72 million; however this can be considerably higher during drought years (Clarke et al. 2021). This impact is chronic, causing reduced wheat yields even in the face of agricultural innovation. Reversing soil degradation and restoring fertility by 2030 is an aim of the government's 25 Year Environment Plan, using mechanisms such as the proposed Environmental Land Management scheme which aims to reward farmers for protecting and regenerating soils. However, current trends suggest continued soil health decline (Environment Agency, 2023). 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 and food security in the longer term if yield losses cannot be offset through imports (e.g. due to concurrent soil health decline in other countries).

Compounding threats: Air pollution from wildfires; Algal blooms; AMR, Biodiversity and mental health; **Direct damage from wildfires;** Freshwater pollution; Grain crops pest/pathogen; **Global food security repercussions;** Flooding; **Loss of pollinators; MBBF;** Risks to tourism; **Sitka spruce pest;** Net zero policies; Global food supply chain interruption from biodiversity-climate policy misalignment; **Business impacts due to UK-only biodiversity policies;** Housing asset risks, Corporate litigation; Other factors: Drought, flood, geopolitical factors - e.g. reduced Ukraine wheat production, and reduced supply of chemical fertilisers. Soli damage also worsens climate change as intensive agriculture has caused arable soils to lose about 40 to 60% of their organic carbon (note, UK soils currently store about 10 billion tonnes of carbon, roughly equal to 80 years of annual UK greenhouse gas emissions (Environment Agency, 2023). When soils become compacted, they are more likely to become waterlogged and experience surface ponding that leads to run-off and flooding, as well as increasing nutrient run off exacerbating eutrophication of watercourses.

Risk title: 29) Zoonotic disease
One sentence risk description: Disease causing pandemic and major economic and financial disruption
Risk type: Physical
Risk source and timeframe: Domestic and transboundary, acute
Plausible worst case scenario: A global pandemic emerges with greater mortality than COVID-19 causing widespread systemic economic disruption. The pandemic arises from intensive livestock or poultry systems and rapidly spreads through the international transport network. As a consequence of previous pandemics and from funding recovery from repeated extreme climate events (UNEP, 2021) among other issues, governments have limited financial capital to buffer economic impacts (e.g. furlough schemes).

Rationale for likelihood: Covid-19 led to 24.6M confirmed cases in the UK, 220,721 deaths, with 0.9% case fatality leading to 325 deaths per 100k of population (JHU Coronavirus Resource Center (2023). A 'plausible worst case' for a future pandemic could easily involve double or triple this country-level mortality. This is still conservative since avian influenza in humans has a 56% fatality rate (WHO, 2023). Pro-active vaccine development has been ramped up globally so there is no reason to think that the vaccine development time would be longer (Chatham House, 2022a). Ecosystem damage increases zoonotic disease emergence risk (IPBES 2020). For example, deforestation for cattle ranching leads to increased emergence of wildlife diseases. Damage to ecosystems means food shortages and increased reliance on bushmeat, whereby unregulated markets increase risks (SysRisk, 2021). Food shortages (and net zero transitions) leads to intensification of the livestock and poultry industries with higher disease risk (SyRisk, 2021). Globalised transport connectivity leads to rapid expansion of novel diseases (Baker et al. 2022). Rationale for impact: Covid-19 led to 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.

Compounding threats: AMR; Biodiversity and mental health; Deforestation; Global food security repercussions; Freshwater pollution; Flooding; MBBF; Risks to tourism; **Livestock disease;** Net zero policies; Global food supply chain interruption from biodiversity-climate policy misalignment; Business impacts due to UK-only biodiversity policies; Housing asset risks; Other factors: Extreme weather events occurring at the same time as pandemic would exacerbate impacts substantially. They can also increase emergence risks, for example, 1998 El Niño weather event caused flooding in West Africa meaning cattle and humans were forced to live closer together on the remaining dry land, increasing risk of cross-species pathogen transmission (Chatham House, 2022a). Climate change can also increase frequency of vectors such as mosquitoes. Large scale, uncontrolled immigration and misinformation can also hamper disease control.

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