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Climate Change and Security

Climate change is creating complex risks for societies,[1] with globalisation increasing dependencies and interconnectedness between nations. This POSTnote sets out the potential security implications of climate change, arising from both its impacts on human systems and the 'transition risks' from climate change mitigation measures. It also describes the tools and approaches that could be used to manage the risks and opportunities arising.

Overview

- Climate change has impacted health, livelihoods, wildlife, infrastructure, and economies across the world. The globalised economy can propagate these impacts, exacerbating challenges in other regions.
- Both mitigating and adapting to climate change brings risks and opportunities. For example, transitioning to renewable energy technologies provides opportunities for diplomacy and economic growth.
- Deep uncertainties in complex risks limits the predictive capacities of new technologies such as Machine Learning.
- Decision making under uncertainty requires intelligence on local contexts, expert input, and scenario-building exercises.
- Building general resilience across complex systems reduces these risks. Best practice principles could guide institutional processes and its governance at different levels.

Background

The Intergovernmental Panel on Climate Change (IPCC) has stated global warming is making extreme weather events, such as heatwaves, droughts, and extreme rainfall, more frequent and intense worldwide.[2–4] It is also causing longer-term changes such as sea level rise (PN 555)[5] and biodiversity loss.[6,7] Studies suggest the impacts of climate change may push 100m people into extreme poverty by 2030, and 720m by 2050.[8,9]

Changes in the frequency and intensity of climate hazards (the potential occurrence of climate-related physical events or trends that may cause damage or loss)[10] are becoming increasingly well understood.[4] Climate risks to society are defined by a combination of the level and nature of climate hazards and the exposure and vulnerability of the local population, natural and built environments.[11] This combination results in a complex and challenging picture of risks: there are several types of climate hazards, which act over different areas and timescales, and have different uncertainties and non-linear responses to a warming climate.[4] In addition, growing and aging populations, critical national infrastructure, poverty, geopolitics, and other factors interact with climate change to create shifting and interconnected risks. These can all interact to amplify impacts, sometimes referred to as compound risks.[12]

Security implications of climate change

Broadly, there are two main ways in which climate change may affect the security of societies around the world:

- **Climate change risks:** Climate impacts on key sectors and regions, such as multiple agricultural areas,[13] can cascade through global supply chains.[14–16] This can affect prices worldwide[17] and exacerbate existing security tensions.[18,19] National and international security organisations refer to climate change as a 'threat multiplier'.[1,20,21] Effective adaptation measures may reduce the risk of societal disruption by allaying impacts, but not all can be avoided.[21] The UK Government was advised on these risks ahead of its 3rd 5-yearly Climate Change Risk Assessment.[22,23]
- **Transition risks:** Climate change mitigation policies may carry their own risks. For example, global reductions in greenhouse gas emissions require major economic shifts. Demand for fossil fuels will decrease, while increasing for materials used in renewable technologies (PB 45). This will affect nations' financial stability and geopolitical relations.[24,25]

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Climate change risks

Climate change amplifies a variety of potential security risks domestically and overseas, including food,[26,27] water,[28,29] and biosecurity[30–32] risks (PN 626, PB 40, PN 660). However, in 2021, the Committee on Climate Change (CCC) concluded that the Government's 2018 National Adaptation Programme had "no actions to respond to the risks from climate change overseas."[33] This issue is now gathering parliamentary interest: the Joint Committee on the National Security Strategy is investigating domestic climate change risks to critical national infrastructure, and the Environment, Food and Rural Affairs Committee is investigating UK food security.[34] This section outlines how risks could affect the UK, through international supply chains, migration, and conflict.

Supply chains

Supply chains cross international boundaries, creating interconnected networks of trade that often optimises efficiency above robustness.[35] Small shocks may have limited effects, but larger impacts can ripple throughout the system amplifying the impacts to other regions and sectors, both public and private. These are referred to as cascading risks (Box 1). Climate change may increase the frequency or scale of cascading risks.[36] For instance, extreme weather in key trade nodes, such as the Panama canal[37,38] and critical ports,[39] as well as concentrated production hubs, such as semiconductor manufacturing in Taiwan, could lead to cascading impacts throughout the supply chain.[40,41] Most critical infrastructure, such as power and food systems, depends on international supply chains, providing many avenues for climate impacts to cause widespread disruption and systemic risks (Box 1).

A key vulnerability in supply chains is a lack of data (PN 626),[42–44] preventing climate risk assessments.[45] For example, in 2011 flooding in Thailand affected several major industrial estates simultaneously, causing unforeseen cascading disruption leading to losses of over $40 billion globally.[46,47] In 2022, the UK introduced mandatory climate-related financial disclosure regulations,[48,49] but there are no established international frameworks (PN 667).[50] The Department for International Trade recently created the Global Supply Chains Directorate to address supply chain risks.[22]

Migration and displacement

Currently, 80% of all migration globally is internal, including both voluntary migration and forced displacement.[51] No general causal link between climate change and the movement of people has yet been established and climate effects may exacerbate or restrict movement in different situations.[51–54] Numerous factors contribute to each case of people leaving their homes, including local dynamics, socioeconomic effects, governance, and the vulnerability of institutions and communities to climate change effects.[55–57]

Poorly managed movement already leads to an array of risks. Commentators suggest these risks include greater resource competition, heightened cultural tensions, and exploitation by criminal and terrorist organisations.[21] As refugee status is limited to political persecution, environmental migrants have limited rights, creating several vulnerabilities.[58–60]

As thresholds such as survivable temperatures are exceeded more frequently,[67] adapting to these changes will become prohibitively expensive or impossible. Regions with a combination of high vulnerability and population density, such as South Asia and West Africa, are at acute risk. By 2070, 1-3 billion people will experience average yearly temperatures of 29 °C, currently found only in sparsely habited parts of the Sahara,[52] and hundreds of millions will be affected by sea level rise,[68] depending on migration and climate mitigation.

Box 1: Cascading and systemic risks

Cascading risks occur when an adverse impact triggers or amplifies other risks.[61] For instance, in 2010 western Russia experienced an unprecedented heatwave, drought, and series of wildfires, destroying 17% of the wheat harvest. Russia banned wheat exports, resulting in sharp international price rises.[62,63] This led to increased food bank usage in the UK and a rise in poverty and political unrest in countries such as Egypt, Tunisia and Mozambique.[64] This was one of many factors that contributed to the Arab Spring in 2011.[65] Risk cascades can be triggered when a physical threshold is crossed. For example, reaching a specific temperature and dryness that cause widespread crop death. Climate change increases the likelihood of crossing thresholds and doing so in different regions simultaneously. For example, climate change is increasing the chance of co-occurring crop failure for many staple crops including wheat, soybeans, and maize across key agricultural areas,[66] which would have a disproportionate global food security impact. This may pose systemic risks, in which entire systems collapse,[36,61] such as political institutions or business sectors.

Conflict and military challenges

Climate change impacts may aggravate underlying drivers of conflict, including poverty, inequality, marginalisation, and existing tensions between groups, within or between states.[69–72] The security outcomes of climate change will be determined by these factors and the resilience of the systems affected.[21,73] The most rapid and severe impacts are occurring in more vulnerable states with weaker governance systems.[20,65,69,74] However, further adaptation in these regions could minimise security implications.[21,73]

Conflict causes environmental damage via collateral destruction and military emissions.[75–77] It may also shift policy priorities away from environmental objectives and the international cooperation required to achieve them.[78] Simultaneous conflict and extreme climate events in separate regions can have impacts that cascade, reinforce one another, and are difficult to reverse (Box 2).[72] Increasingly, national defence organisations including the US Department of Defense are factoring climate change into planning and operations.[79] The UK military will face greater demands on its resources as a first responder to disasters, including domestically and internationally.[80] For example, in 2019 the Royal Navy provided emergency relief in the aftermath of Hurricane Dorian in the Caribbean.[80] In future, similar relief may need to be delivered globally where UK interests are affected. Military bases and infrastructure will be increasingly impacted by sea level rise (PB 25), and climate events pose risks to operations.[79] Climate change is also altering geostrategic environments, such as the Arctic.[81] The Defence Select Committee is investigating the role of climate change in conflict and the implications for defence.[82]

Box 2: Ukraine conflict and compounding crises
Both Ukraine and Russia are major exporters of wheat. As a result of the conflict, a significant quantity of wheat has perished without harvesting or is being held under Russian control. Food prices are rising globally, forming an evolving cascading risk (Box 1). The consequences are similar to the loss of the Russian harvest in 2010, showing how different events can have similar results in interconnected systems. Climate change also exacerbates existing global challenges by increasing the likelihood of co-occurring crises. In 2022, the loss of wheat from Ukraine and Russia has been compounded by the depleted harvest in India.[83] This was caused by a climate change-driven heatwave and drought from March-May,[84] pushing food prices higher. Many current climate impacts are manifesting in nations with a larger fraction of primary industries, such as agriculture.[85,86]

Transition risks

The introduction of climate change mitigation policies can carry different risks. For example, a mostly renewable energy system may be more vulnerable to cyber-attacks due to their greater connectivity (PN 655, PN 676). However, renewable systems are less vulnerable in other ways - a disrupted supply of materials means components are replaced more slowly and causes limited price rises, but in a fossil fuel system price is heavily affected by shocks.[87,88] The process of transitions presents other risks. In the long term, as demand reduces for fossil fuels, some nations will lose tax revenues and geopolitical power, and others will gain.[89] This may affect nations with high fiscal dependency on foreign revenues for those resources, such as Nigeria or Middle-Eastern states.[90] Risks for financial institutions may increase as fossil fuel assets become 'stranded' and if disorderly transitions to Net Zero occur, with a risk the assets may become contingent liabilities for nation states.[91]

Control of key material resources and supply chains will become of greater geopolitical concern as renewable energy technologies grow (PN 609).[25,92–94] These resources include both bulk and rare earth metals (PB 45). China currently mines approximately 60%[95] and refines approximately 90%[96] of rare earth elements globally, and has influence over 50% of total global reserves.[97] Russia also contains a wealth of rare earth elements,[95] as does the Ukraine,[98,99] which signed a critical materials deal with the EU in July 2021.[100] In July 2022, the Government opened the Critical Minerals Intelligence Centre and published its strategy to ensure future supply.[94,101]

Managing security risks and opportunities

Security has previously been defined via the lens of protecting national borders, and the interactions of states and ideologies. However, climate change is not a conventional security threat as it is non-human and transcends borders, like pandemics. Researchers and security experts suggest that a new global approach to security is required that encompasses potential responses to climate change,[20] such as extending it to include the global governance of adaptation.[11] Co-defining this new approach with a range of state and non-state actors would allow the incorporation of different meanings of security to various groups, nations and cultures. It is suggested a definition based on human security and the global commons could deliver mutual security benefits to nation states.[102,103]

Managing the security implications of climate change may also present other opportunities, such as innovation in financial risk services.[104] It also provides a pathway towards international diplomacy, through enhanced development, collaboration on adaptation, and intelligence-sharing. However, poorly implemented adaptation measures can increase climate risks, known as 'maladaptation'.[105,106] Short term adaptation measures can also lead to greater risks in the longer term, such as adapting communities to sea level rise as opposed to moving them entirely.[107] To predict and manage security risks, and avoid maladaptation, new tools and approaches are needed.

Emerging technologies and methods

New and abundant sources of data are now available, such as satellite images and social media, which can aid in monitoring and predicting risks, although uncertainties are inherent in complex systems. The volume and variety of data types makes analysis challenging, and the availability of data varies globally.

Machine Learning (ML)

ML can be used to identify patterns in large sets of data that would be difficult for a human analyst (PN 628). This aids the study of complex risks in many ways. It can help to infer missing data in supply chains and critical regions,[108–110] and to study systems such as cities or critical infrastructure in greater detail.[111,112] 'Internet of things' data can also be used by ML to make more reliable predictions.[112,113] Finally, research suggests that ML can identify and forecast tipping points[114,115] in complex systems when the underlying mechanisms are understood.[116]

Commentators caution that ML can give false precision,[117,118] and there are many types of data that cannot be integrated into Artificial Intelligence systems or are unknown.[119] For instance, in every case of conflict, local dynamics and cultural factors down to the individual scale could be crucial but unknown.[120] Overall, ML methods can use big data to aid understanding of complex systems, but prediction of conflicts may require human understanding of the specific context.[121]

Climate, economic, and system modelling

In many regions, accurate seasonal forecasts are becoming available earlier.[122,123] Understanding plausible future seasons aids appropriate planning when combined with an understanding of the impacts for societal systems. Climate projections are also being used to manage risks. In Sub-Saharan Africa, an initiative by a global research partnership is using climate and food production models for nutrition security projections for local policymakers.[124]

Traditional economic models are limited in their ability to model complex behaviour and rapid transformations under future climate change.[125–128] Newer 'agent-based' models do this by simulating the relationships between thousands of different economic actors with individual priorities,[126,129] and are used to study the complex emergent behaviour of the system.[130] Like ML, the usefulness of these models depends on the extent of the underlying data and understanding. Digital twins are digital representations of a specific asset or system, such as a dam or a city, used for stress-testing (PN 656). These may provide an effective tool for decision making on a rapid timescale.[131] Combining individual digital twins to highlight co-dependencies can be used for more sophisticated systems.[131,132]

Scenario building and risk-opportunity analysis

Climate policy decisions often have transformative and unpredictable results beyond the scope of traditional cost-

benefit analysis and modelling.[133,134] 'Scenario-focused decision analysis'[135] is a way to inform decision making in the face of irreducible uncertainty.[127] Plausible scenarios are constructed using expert advice from a range of stakeholders and modelling evidence (PN 332).[36,136] One such approach is risk-opportunity analysis, in which all significant options and their benefits and risks are transparently considered. This is useful when their relative probabilities and outcomes cannot be quantified, and when decisions involve complex risk or benefit trade-offs.[133,137]

Defence sector trends

The defence sector is increasingly investing in AI methods. The MoD DSTL GUARD project[138] is a digital network of over 8000 global cities, mapping the relationship between a range of political and cultural factors to understand tension and conflict pathways.[139] Research is ongoing to integrate the risks of climate thresholds into this system. Some experts suggest that this may lack the value of traditional intelligence gathering of in-situ data and the transparency of expert advice.[140]

Building general resilience

Resilience has multiple definitions (PN 626), but general resilience of a system is defined by its robustness to shocks, and its ability to recover from them and reorient to avoid future shocks, including novel and unforeseen ones.[141] Building general resilience across systems can mitigate highly complex and unpredictable risks, such as distributing the production of key crops, locally and internationally, to avoid large impacts (PN 626). There is a range of best-practice principles and governance processes to guide institutions at different levels.

Principles and approaches

Changes in both supply and demand pose risks to systems. Supply-side risks are mitigated through a range of principles, such as ensuring a diverse array of suppliers or substitutable materials, among others.[61] Commentators suggest that general resilience is best implemented across trade networks through regulation.[142–145] Current measures mostly focus on maintaining supply, but careful changes in demand, such as dietary changes, also mitigate the risks of shocks and stresses.[141] Measures taken across the value chain are complementary. Research suggests that more efficient resource use to reduce material consumption (PN 646) could reduce risks further,[141] with ongoing research into best practice.[146,147]

Building general resilience to climate risks often requires effective international development,[148] which links defence, development and diplomacy.[21] The UK military has planning, engineering, and risk governance expertise, but there may be negative local attitudes to militaries in some countries.[20] Evidence suggests development measures are most effective and equitable if community co-created, co-implemented and owned.[21,149] Not accounting for local dynamics and contexts may lead to wasted resources and maladaptation.[20] The cross-cutting nature of climate security suggests the need for greater collaboration within and between Governments, academia, and industry and NGO practitioners.[11,150,151] Researchers suggest universities continue to be siloed into traditional disciplines, and new approaches are required to translate research into practical action at scale. Research councils and organisations such as the Alan Turing Institute encourage interdisciplinary work,[152] but the challenges highlight the need for transdisciplinary research involving practitioners and policymakers[153] (PN 543, Box 3). At a global scale, collaboration and partnerships on supply chains resilience could provide long-term energy and climate security.

Box 3: Centre for Climate Security

In May 2022, NATO announced a new Climate Change and Security Centre of Excellence, based in Montreal.[154] The Alan Turing Institute have suggested that the UK should have its own similar institution,[155] to cohere efforts between Government departments. This aligns with select committee recommendations for an 'Office for Preparedness and Resilience'.[156] It could bring together experts from defence, policy, law, NGOs, academia, and sectors including finance and logistics to provide climate security advice including:

- **Long-term strategic view:** Horizon-scanning and foresight activities to consider the security implications of climate change beyond the existing 5-year policy cycle.[157]
- **Complexity science:** Moving from an individual-centric to system-wide view to provide a more accurate view of societal dynamics, such as cascading risks.[158]
- **Diversity of voices:** Bringing together the breadth of knowledge, perspectives and skillsets needed to address complex challenges through inclusive dialogue.[159,160]
- **Knowledge exchange:** Creating avenues for policymakers and industry to collaborate with academia, to ensure analysis is tailored towards critical challenges.[161]
- **Co-creating tools for decision making:** Combining new technologies with expert elicitation to inform plausible scenarios in the face of deep uncertainty.[127]

Governance processes

There are existing international mechanisms that could be used to address climate security risks in multiple ways.[22,162] Current finance levels for adaptation are inadequate compared to what research and developing countries state is required.[152–154] Legal governance of such challenges to the global commons have precedents, such as conventions on Maritime and Humanitarian Law.[163,164] Further precedents exist for international data sharing, through the World Health Organisation, and for incorporating the views of non-state actors into UN processes, as in recent compacts.[165] As a member of NATO and the UN Security Council, the UK has a role in ensuring these have the legitimacy and capacity to support vulnerable regions.[69,80,166]

At the national level, the Climate Change Act 2008 mandates the Government to monitor and adapt to climate risks, and grants the Government the Adaptation Reporting Power for public service providers.[22] This has only been used as a mandatory requirement once and the two most recent rounds of reporting have been voluntary.[33] The Government is considering climate risks through the Integrated Review,[167] the National Adaptation Programme and devolved administrations' equivalents,[168–171] the International Development Strategy,[172] and the National Resilience Strategy. The CCC suggests that no single department owns climate risks and cross-departmental working is critical.[23] The MoD and the US Department of Defense now integrate climate change throughout their decision making.[79,80] A possible national policy approach is exemplified in a Centre for Climate Security (Box 3).

Many climate impacts and security implications are local. Local resilience forums are multi-agency partnerships responsible for community-level resilience in England.[173] However, they lack risk information, a forum for information sharing, and powers to respond to impacts.[156] This means they currently cannot add local value to national plans.[156]

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1. Gerson, N. L. *et al.* (2007). *National Security and the Threat of Climate Change.* 35. The CNA Corporation.
2. Fischer, E. M. *et al.* (2015). Anthropogenic contribution to global occurrence of heavy-precipitation and high-temperature extremes. *Nat. Clim. Change*, Vol 5, 560–564.
3. Clarke, B. *et al.* (2022). Extreme weather impacts of climate change: an attribution perspective. *Environ. Res. Clim.*, Vol 1, 012001. IOP Publishing.
4. IPCC, 2021: Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, In press, doi:10.1017/9781009157896.
5. Dangendorf, S. *et al.* (2019). Persistent acceleration in global sea-level rise since the 1960s. *Nat. Clim. Change*, Vol 9, 705–710. Nature Publishing Group.
6. Habibullah, M. S. *et al.* (2022). Impact of climate change on biodiversity loss: global evidence. *Environ. Sci. Pollut. Res.*, Vol 29, 1073–1086.
7. IPBES (2019): Global assessment report on biodiversity and ecosystem services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services. E. S. Brondizio, J. Settele, S. Díaz, and H. T. Ngo (editors). IPBES secretariat, Bonn, Germany. 1148 pages. https://doi.org/10.5281/zenodo.3831673
8. Granoff, I. *et al.* (2015). *Zero poverty, zero emissions.* 56. Overseas Development Institute.
9. Hallegatte, S. *et al.* (2016). *Shockwaves: Managing the Impacts of Climate Change on Poverty.* The World Bank.
10. IEA (2022). Climate Resilience Policy Indicator. *IEA*.
11. IPCC, 2022: Climate Change 2022: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [H.-O. Pörtner, D.C. Roberts, M. Tignor, E.S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, B. Rama (eds.)]. Cambridge University Press. In Press.
12. Zscheischler, J. *et al.* (2018). Future climate risk from compound events. *Nat. Clim. Change*, Vol 8, 469.
13. Zhao, C. *et al.* (2017). Temperature increase reduces global yields of major crops in four independent estimates. *Proc. Natl. Acad. Sci.*, Vol 114, 9326–9331.
14. Ghadge, A. *et al.* (2020). Managing climate change risks in global supply chains: a review and research agenda. *Int. J. Prod. Res.*, Vol 58, 44–64. Taylor & Francis.
15. Pescaroli, G. *et al.* (2018). Understanding and mitigating cascading crises in the global interconnected system. *Int. J. Disaster Risk Reduct.*, Vol 30, 159–163.
16. Davis, K. F. *et al.* (2021). Towards food supply chain resilience to environmental shocks. *Nat. Food*, Vol 2, 54–65. Nature Publishing Group.
17. Gaupp, F. (2020). Extreme Events in a Globalized Food System. *One Earth*, Vol 2, 518–521.
18. Simpson, N. P. *et al.* (2021). A framework for complex climate change risk assessment. *One Earth*, Vol 4, 489–501.
19. Lunt, T. *et al.* (2016). Vulnerabilities to agricultural production shocks: An extreme, plausible scenario for assessment of risk for the insurance sector. *Clim. Risk Manag.*, Vol 13, 1–9.
20. Goodman, S. *et al.* (2021). *World Climate and Security Report 2021.* International Military Council on Climate Security.
21. Rüttinger, L. *et al.* (2015). *A New Climate For Peace: Taking Action on Climate and Fragiliy Risks.* Adelphi.
22. HM Government (2022). *UK Climate Change Risk Assessment 2022.*
23. Brown *et al.* (2021). Independent Assessment of UK Climate Risk. Committee on Climate Change.
24. Kleijn, R. *et al.* (2011). Metal requirements of low-carbon power generation. *Energy*, Vol 36, 5640–5648.
25. Vidal, O. *et al.* (2013). Metals for a low-carbon society. *Nat. Geosci.*, Vol 6, 894–896. Nature Publishing Group.
26. Falloon, P. *et al.* (2022). What do changing weather and climate shocks and stresses mean for the UK food system? *Environ. Res. Lett.*, Vol 17, 051001. IOP Publishing.
27. Wheeler, T. *et al.* (2013). Climate Change Impacts on Global Food Security. *Science*, Vol 341, 508–513. American Association for the Advancement of Science.
28. Watts, G. *et al.* (2015). Climate change and water in the UK – past changes and future prospects. *Prog. Phys. Geogr. Earth Environ.*, Vol 39, 6–28. SAGE Publications Ltd.
29. Koutroulis, A. G. *et al.* (2019). Global water availability under high-end climate change: A vulnerability based assessment. *Glob. Planet. Change*, Vol 175, 52–63.
30. Skendžić, S. *et al.* (2021). The Impact of Climate Change on Agricultural Insect Pests. *Insects*, Vol 12, 440. Multidisciplinary Digital Publishing Institute.
31. Iwamura, T. *et al.* (2020). Accelerating invasion potential of disease vector Aedes aegypti under climate change. *Nat. Commun.*, Vol 11, 2130. Nature Publishing Group.
32. Caminade, C. *et al.* (2019). Impact of recent and future climate change on vector-borne diseases. *Ann. N. Y. Acad. Sci.*, Vol 1436, 157–173.
33. Committee on Climate Change (2021). *Progress in adapting to climate change.*
34. Food Security - Committees - UK Parliament.
35. Woetzel, J. *et al.* (2020). Could climate become the weak link in your supply chain? | McKinsey.
36. Quiggin, D. *et al.* (2021). *Climate change risk assessment 2021.* 53. Chatham House.
37. Aguilar, G. *et al.* (2022). The Panama Canal. in *El Niño Ready Nations and Disaster Risk Reduction: 19 Countries in Perspective*. (ed. Glantz, M. H.) 347–360. Springer International Publishing.
38. Oxford Analytica (2020). Worsening drought threatens Panama Canal. *Emerald Expert Brief.*,
39. Izaguirre, C. *et al.* (2021). Climate change risk to global port operations. *Nat. Clim. Change*, Vol 11, 14–20. Nature Publishing Group.
40. Aviso, K. B. *et al.* (2021). Taiwan Drought was a Microcosm of Climate Change Adaptation Challenges in Complex Island Economies. *Process Integr. Optim. Sustain.*, Vol 5, 317–318.
41. Chang, M.-F. *et al.* (2021). The role of government policy in the building of a global semiconductor industry. *Nat. Electron.*, Vol 4, 230–233. Nature Publishing Group.
42. Leat, P. *et al.* (2013). Risk and resilience in agri-food supply chains: the case of the ASDA PorkLink supply chain in Scotland. *Supply Chain Manag. Int. J.*, Vol 18, 219–231. Emerald Group Publishing Limited.
43. Trienekens, J. H. *et al.* (2012). Transparency in complex dynamic food supply chains. *Adv. Eng. Inform.*, Vol 26, 55–65.
44. Bastian, J. *et al.* (2013). Supply chain transparency as a key prerequisite for sustainable agri-food supply chain management. *Int. Rev. Retail Distrib. Consum. Res.*, Vol 23, 553–570.
45. Fiedler, T. *et al.* (2021). Business risk and the emergence of climate analytics. *Nat. Clim. Change*, Vol 11, 87–94. Nature Publishing Group.
46. Gale, E. L. *et al.* (2013). The 2011 Thailand flood: climate causes and return periods. *Weather*, Vol 68, 233–237.
47. Haraguchi, M. *et al.* (2015). Flood risks and impacts: A case study of Thailand's floods in 2011 and research questions for supply chain decision making. *Int. J. Disaster Risk Reduct.*, Vol 14, 256–272.

48. Department for Business, Energy & Industrial Strategy (2022). *Mandatory climate-related financial disclosures by publicly quoted companies, large private companies and LLPs.*
49. HM Government (2021). *Greening Finance: A Roadmap to Sustainable Investing.*
50. World Economic Forum (2022). *The Global Risks Report 2022.*
51. Government Office for Science (2011). *Foresight: Migration and Global Environmental Change.*
52. Xu, C. *et al.* (2020). Future of the human climate niche. *Proc. Natl. Acad. Sci.*, Vol 117, 11350–11355. Proceedings of the National Academy of Sciences.
53. Black, R. *et al.* (2011). The effect of environmental change on human migration. *Glob. Environ. Change*, Vol 21, S3–S11.
54. Wu, Y. (2022). Climate change will make it harder for world's poorest to migrate, study says. *Carbon Brief*.
55. von Uexkull, N. *et al.* (2021). Security implications of climate change: A decade of scientific progress. *J. Peace Res.*, Vol 58, 3–17. SAGE Publications Ltd.
56. Boas, I. *et al.* (2019). Climate migration myths. *Nat. Clim. Change*, Vol 9, 901–903. Nature Publishing Group.
57. IPCC, 2022: Climate Change 2022: Mitigation of Climate Change. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [P.R. Shukla, J. Skea, R. Slade, A. Al Khourdajie, R. van Diemen, D. McCollum, M. Pathak, S. Some, P. Vyas, R. Fradera, M. Belkacemi, A. Hasija, G. Lisboa, S. Luz, J. Malley, (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA. doi: 10.1017/9781009157926
58. Nukusheva, A. *et al.* (2021). Global warming problem faced by the international community: international legal aspect. *Int. Environ. Agreem. Polit. Law Econ.*, Vol 21, 219–233.
59. McLeman, R. (2019). International migration and climate adaptation in an era of hardening borders. *Nat. Clim. Change*, Vol 9, 911–918. Nature Publishing Group.
60. Kälin, W. (2015). *The Nansen Initiative: building consensus on displacement in disaster contexts.* 3. Nansen Initiative.
61. Kemp, L. (2021). *The Cascading Climate Crisis.* Cambridge Open Exchange.
62. Welton, G. (2010). *The Impact of Russia's 2010 Grain Export Ban.* Oxfam.
63. Christian, J. I. *et al.* (2020). Flash drought development and cascading impacts associated with the 2010 Russian heatwave. *Environ. Res. Lett.*, Vol 15, 094078. IOP Publishing.
64. Hunt, E. *et al.* (2021). Agricultural and food security impacts from the 2010 Russia flash drought. *Weather Clim. Extrem.*, Vol 34, 100383.
65. Werrell, C. E. *et al.* (2013). *The Arab Spring and Climate Change.* 68. Centre for American Progress.
66. Gaupp, F. *et al.* (2020). Changing risks of simultaneous global breadbasket failure. *Nat. Clim. Change*, Vol 10, 54–57. Nature Publishing Group.
67. McLeman, R. (2018). Thresholds in climate migration. *Popul. Environ.*, Vol 39, 319–338.
68. Neumann, B. *et al.* (2015). Future Coastal Population Growth and Exposure to Sea-Level Rise and Coastal Flooding - A Global Assessment. *PLOS ONE*, Vol 10, e0118571. Public Library of Science.
69. Government Office for Science (2011). *Foresight: International dimensions of climate change.*
70. Koubi, V. (2019). Climate Change and Conflict. *Annu. Rev. Polit. Sci.*, Vol 22, 343–360.
71. Busby, J. (2019). *The Field of Climate and Security: A Scan of the Literature.* 18. Social Science Research Council.
72. Sun, S. C. *et al.* (2022). Revealing the Excitation Causality between Climate and Political Violence via a Neural Forward-Intensity Poisson Process. in Vol 6, 5171–5177.
73. Department of Defense, Office of the Undersecretary for Policy (Strategy, Plans, and Capabilities) (2021). Department of Defense Climate Risk Analysis. 18.
74. Eckstein, D. *et al.* (2021). *Global Climate Risk Index 2021.* Germanwatch.
75. Khan, M. (2022). *The Environmental Impacts of War and Conflict.* 13. K4D Helpdesk Report. Institute of Development Studies.
76. Pereira, P. *et al.* (2022). Russian-Ukrainian war impacts the total environment. *Sci. Total Environ.*, Vol 837, 155865.
77. Solomon, N. *et al.* (2018). Environmental impacts and causes of conflict in the Horn of Africa: A review. *Earth-Sci. Rev.*, Vol 177, 284–290.
78. Deng, M. *et al.* (2022). *The Russia-Ukraine War and Climate Policy Expectations: Evidence from the Stock Market.* Swiss Finance Institute.
79. Department of Defense, Office of the Undersecretary of Defense (Acquisition and Sustainment). (2021). *Department of Defense Draft Climate Adaptation Plan.*
80. Ministry of Defence (2021). *Climate Change and Sustainability Strategic Approach.*
81. "Climate Change and Security in the Arctic." A product of The Center for Climate and Security (CCS), an institute of the Council on Strategic Risks (CSR), and The Norwegian Institute of International Affairs (NUPI). Authors: Sherri Goodman, Kate Guy, Marisol Maddox (CCS); Vegard Valther Hansen, Ole Jacob Sending, Iselin Németh Winther (NUPI). Edited by Francesco Femia and Erin Sikorsky (CCS). January 2021.
82. Defence and Climate Change - Committees - UK Parliament.
83. Bal, S. *et al.* (2022). *Heat Wave 2022: Causes, impacts and way forward for Indian Agriculture.* ICAR - Central Research Institute for Dryland Agriculture.
84. Rashid, I. U. *et al.* (2022). Early summer surface air temperature variability over Pakistan and the role of El Niño–Southern Oscillation teleconnections. *Int. J. Climatol.*, joc.7560.
85. Ahmadalipour, A. *et al.* (2019). Future drought risk in Africa: Integrating vulnerability, climate change, and population growth. *Sci. Total Environ.*, Vol 662, 672–686.
86. Byers, E. *et al.* (2018). Global exposure and vulnerability to multi-sector development and climate change hotspots. *Environ. Res. Lett.*, Vol 13, 055012. IOP Publishing.
87. Månberger, A. *et al.* (2018). Global metal flows in the renewable energy transition: Exploring the effects of substitutes, technological mix and development. *Energy Policy*, Vol 119, 226–241.
88. Pagliaro, M. (2019). Renewable Energy Systems: Enhanced Resilience, Lower Costs. *Energy Technol.*, Vol 7, 1900791.
89. Bazilian, M. *et al.* (2020). Four scenarios of the energy transition: Drivers, consequences, and implications for geopolitics. *WIREs Clim. Change*, Vol 11, e625.
90. Audu, A. *et al.* (2016). Economics and environmental impacts of oil exploration and exploitation in Nigeria. *Energy Sources Part B Econ. Plan. Policy*, Vol 11, 251–257. Taylor & Francis.
91. Bank of England (2022). *The Bank of England's climate-related financial disclosure 2022.*
92. Lee, Y. *et al.* (2022). Reducing the United States' risks of dependency on China in the rare earth market. *Resour. Policy*, Vol 77, 102702.
93. Schmid, M. (2019). Mitigating supply risks through involvement in rare earth projects: Japan's strategies and what the US can learn. *Resour. Policy*, Vol 63, 101457.

94. HM Government (2022). UK's first Critical Minerals Intelligence Centre to help build a more resilient economy. *GOV.UK*.
95. U.S. Geological Survey (2022). *Mineral Commodity Summaries*.
96. International Energy Agency (2022). *The Role of Critical Minerals in Clean Energy Transitions*.
97. Barakos, G. *et al.* (2018). The Potentials of Scientific and Industrial Collaborations in the Field of REE through China's Belt and Road Initiative. *Int. J. Georesources Environ.*, Vol 4,
98. Ukrainian Geological Survey (2021). *UKRAINE: Investment Opportunities in Exploration & Production*.
99. Lazard, O. (2022). Russia's Lesser-Known Intentions in Ukraine. *Carnegie Europe*.
100. Directorate-General for Internal Market, Industry, Entrepreneurship and SMEs (2021). EU and Ukraine kick-start strategic partnership on raw materials. *European Commission*.
101. HM Government (2022). Resilience for the future: The UK's critical minerals strategy. *GOV.UK*.
102. Sawas, A. *et al.* (2018). *Climate change, low-carbon transitions and security*. Grantham Research Institute on Climate Change and the Environment.
103. Morisetti, N. *et al.* (2021). *Mitigating the climate change risks to global security: An opportunity for UK leadership in 2021*. Chatham House.
104. HM Government (2022). *The Business of Resilience Summary Report 2022*. 8. Department for International Trade.
105. Magnan, A. K. *et al.* (2016). Addressing the risk of maladaptation to climate change. *WIREs Clim. Change*, Vol 7, 646–665.
106. Schipper, E. L. F. (2020). Maladaptation: When Adaptation to Climate Change Goes Very Wrong. *One Earth*, Vol 3, 409–414.
107. Hinkel, J. *et al.* (2018). The ability of societies to adapt to twenty-first-century sea-level rise. *Nat. Clim. Change*, Vol 8, 570–578. Nature Publishing Group.
108. Wei, J. *et al.* (2022). Ground-Level NO2 Surveillance from Space Across China for High Resolution Using Interpretable Spatiotemporally Weighted Artificial Intelligence. *Environ. Sci. Technol.*, Vol 56, 9988–9998. American Chemical Society.
109. Zhang, P. *et al.* (2021). Nanotechnology and artificial intelligence to enable sustainable and precision agriculture. *Nat. Plants*, Vol 7, 864–876. Nature Publishing Group.
110. Helo, P. *et al.* (2021). Artificial intelligence in operations management and supply chain management: an exploratory case study. *Prod. Plan. Control*, Vol 0, 1–18. Taylor & Francis.
111. Liu, Y. *et al.* (2020). Generating high-resolution daily soil moisture by using spatial downscaling techniques: a comparison of six machine learning algorithms. *Adv. Water Resour.*, Vol 141, 103601.
112. Chantry, M. *et al.* (2021). Opportunities and challenges for machine learning in weather and climate modelling: hard, medium and soft AI. *Philos. Trans. R. Soc. Math. Phys. Eng. Sci.*, Vol 379, 20200083. Royal Society.
113. Kiran, S. *et al.* (2021). Internet of things integrated smart agriculture for weather predictions and preventive mechanism. *Mater. Today Proc.*,
114. Mackie, E. (2021). *Tipping Points in the Earth System*. Earth and Environmental Sciences.
115. Armstrong McKay, D. I. *et al.* (2022). Exceeding 1.5°C global warming could trigger multiple climate tipping points. *Science*, Vol 377, eabn7950. American Association for the Advancement of Science.
116. Bury, T. M. *et al.* (2021). Deep learning for early warning signals of tipping points. *Proc. Natl. Acad. Sci.*, Vol 118, e2106140118. Proceedings of the National Academy of Sciences.
117. Gilpin, L. H. *et al.* (2018). Explaining Explanations: An Overview of Interpretability of Machine Learning. in *2018 IEEE 5th International Conference on Data Science and Advanced Analytics (DSAA)*. 80–89.
118. Gibney, E. (2022). Could machine learning fuel a reproducibility crisis in science? *Nature*
119. Cederman, L.-E. *et al.* (2017). Predicting armed conflict: Time to adjust our expectations? *Science*, Vol 355, 474–476. American Association for the Advancement of Science.
120. Scheffran, J. (2020). Chapter 16 - Climate extremes and conflict dynamics. in *Climate Extremes and Their Implications for Impact and Risk Assessment*. (eds. Sillmann, J. et al.) 293–315. Elsevier.
121. Knüsel, B. *et al.* (2019). Applying big data beyond small problems in climate research. *Nat. Clim. Change*, Vol 9, 196–202. Nature Publishing Group.
122. Feng, X. *et al.* (2022). A New Approach to Skillful Seasonal Prediction of Southeast Asia Tropical Cyclone Occurrence. *J. Geophys. Res. Atmospheres*, Vol 127, e2022JD036439.
123. Crespi, A. *et al.* (2021). Verification and Bias Adjustment of ECMWF SEAS5 Seasonal Forecasts over Europe for Climate Service Applications. *Climate*, Vol 9, 181. Multidisciplinary Digital Publishing Institute.
124. Jennings, S. *et al.* (2022). A new integrated assessment framework for climate-smart nutrition security in sub-Saharan Africa: the integrated Future Estimator for Emissions and Diets (iFEED). *Front. Sustain. Food Syst.*, Frontiers Media S.A.
125. Czupryna, M. *et al.* (2020). An Agent-Based Approach to Integrated Assessment Modelling of Climate Change. *J. Artif. Soc. Soc. Simul.*, Vol 23, 7.
126. Stern, N. (2016). Economics: Current climate models are grossly misleading. *Nature*, Vol 530, 407–409. Nature Publishing Group.
127. Workman, M. *et al.* (2021). Climate policy decision making in contexts of deep uncertainty - from optimisation to robustness. *Environ. Sci. Policy*, Vol 120, 127–137.
128. DeFries, R. *et al.* (2019). *The missing economic risks in assessments of climate change impacts*. Grantham Research Institute on Climate Change and the Environment.
129. Farmer, J. D. *et al.* (2015). A Third Wave in the Economics of Climate Change. *Environ. Resour. Econ.*, Vol 62, 329–357.
130. Grubb, M. *et al.* (2021). *The New Economics of Innovation and Transition: Evaluating Opportunities and Risks*. 72. ECONOMICS OF ENERGY INNOVATION AND SYSTEM TRANSITION (EEIST) CONSORTIUM.
131. Scott, E. M. (2022). Framing data science, analytics and statistics around the digital earth concept. *Environmetrics*,
132. Blair, G. S. (2021). Digital twins of the natural environment. *Patterns*, Vol 2, 100359.
133. Mercure, J.-F. *et al.* (2021). Risk-opportunity analysis for transformative policy design and appraisal. *Glob. Environ. Change*, Vol 70, 102359.
134. Workman, M. *et al.* (2020). Decision making in contexts of deep uncertainty - An alternative approach for long-term climate policy. *Environ. Sci. Policy*, Vol 103, 77–84.
135. HM Government (2018). *Global Strategic Trends - The Future Starts Today*. 282. Ministry of Defence.
136. Government Office for Science (2017). *The Futures Toolkit: Tools for Futures Thinking and Foresight across UK Government*. 116. HM Government.
137. Sharpe, S. *et al.* (2021). *Deciding how to decide: Risk-opportunity analysis as a generalisation of cost-benefit analysis*. UCL Institute for Innovation and Public Purpose.
138. Global urban analytics for resilient defence. *The Alan Turing Institute*.

139. Guo, W. *et al.* (2018). Retool AI to forecast and limit wars. *Nature*, Vol 562, 331–333.
140. Workman, M. (2022). Personal Communication.
141. Ingram, J. (2021). *Resilience of the UK food system in a global context: key messages for stakeholders.* Global Food Security.
142. Ibn-Mohammed, T. *et al.* (2021). A critical analysis of the impacts of COVID-19 on the global economy and ecosystems and opportunities for circular economy strategies. *Resour. Conserv. Recycl.*, Vol 164, 105169.
143. Koh, L. (2022). Personal Communication.
144. Benton, T. (2022). Personal Communication.
145. Joint Committee on the National Security Strategy (2022). Oral evidence: Global supply chains.
146. Kennedy, S. *et al.* (2022). Circular economy and resilience: A research agenda. *Bus. Strategy Environ.*,
147. Fletcher, C. A. *et al.* (2021). Seafood businesses' resilience can benefit from circular economy principles. *Nat. Food*, Vol 2, 228–232. Nature Publishing Group.
148. Hagen-Zanker, J. *et al. (2016)* Understanding the impact of cash transfers: the evidence. 7.
149. Ziervogel, G. *et al.* (2022). Supporting transformative climate adaptation: community-level capacity building and knowledge co-creation in South Africa. *Clim. Policy*, Vol 22, 607–622. Taylor & Francis.
150. Moallemi, E. A. *et al.* (2020). Achieving the Sustainable Development Goals Requires Transdisciplinary Innovation at the Local Scale. *One Earth*, Vol 3, 300–313.
151. Ebi, K. L. *et al.* (2020). Transdisciplinary Research Priorities for Human and Planetary Health in the Context of the 2030 Agenda for Sustainable Development. *Int. J. Environ. Res. Public. Health*, Vol 17, 8890. Multidisciplinary Digital Publishing Institute.
152. The UK Climate Resilience Programme. *ukclimateresilience.org.*
153. Rigolot, C. (2020). Transdisciplinarity as a discipline and a way of being: complementarities and creative tensions. *Humanit. Soc. Sci. Commun.*, Vol 7, 1–5. Palgrave.
154. Government of Canada (2022). NATO Climate Change and Security Centre of Excellence.
155. Malliaraki, E. *et al.* (2020). *Climate aware and resilient national security: Challenges for the 21st Century.* 63. Turing Institute.
156. Select Committee on Risk Assessment and Risk Planning (2021). *House of Lords - Preparing for Extreme Risks: Building a Resilient Society.*
157. Werrell, C. E. *et al.* (2017). *A Responsibility to Prepare: Governing in an Age of Unprecedented Risk and Unprecedented Foresight.* The Center for Climate and Security.
158. Helbing, D. *et al.* (2015). Saving Human Lives: What Complexity Science and Information Systems can Contribute. *J. Stat. Phys.*, Vol 158, 735–781.
159. Zabaniotou, A. *et al.* (2020). From Multidisciplinarity to Transdisciplinarity and from Local to Global Foci: Integrative Approaches to Systemic Resilience Based upon the Value of Life in the Context of Environmental and Gender Vulnerabilities with a Special Focus upon the Brazilian Amazon Biome. *Sustainability*, Vol 12, 8407. Multidisciplinary Digital Publishing Institute.
160. Sapkota, A. R. (2019). Water reuse, food production and public health: Adopting transdisciplinary, systems-based approaches to achieve water and food security in a changing climate. *Environ. Res.*, Vol 171, 576–580.
161. Daniels, E. *et al.* (2020). Refocusing the climate services lens: Introducing a framework for co-designing "transdisciplinary knowledge integration processes" to build climate resilience. *Clim. Serv.*, Vol 19, 100181.
162. Green Climate Fund (2020). *Updated strategic plan for the green climate fund 2020-2023.*
163. OHCHR, OHRLLS, UNDESA, UNEP, UNFPA (2013). *Global governance and governance of the global commons in the global partnership for development beyond 2015.* United Nations.
164. ICRC (2022). *What is International Humanitarian Law?* International Committee of the Red Cross.
165. UN General Assembly (2019). *Global Compact for Safe, Orderly and Regular Migration.* United Nations.
166. Farhan, A. *et al.* (2022). NATO must prioritize climate change as a security issue. *Chatham House – International Affairs Think Tank*.
167. HM Government (2021). *Global Britain in a competitive age: the integrated review of security, defence, development and foreign policy.*
168. HM Government (2018). *The National Adaptation Programme and the Third Strategy for Climate Adaptation Reporting: Making the country resilient to a changing climate.*
169. National Assembly for Wales, E. (2016). Environment (Wales) Act 2016. Statute Law Database.
170. Scottish Parliament (2009). Climate Change (Scotland) Act 2009. Statute Law Database.
171. DAERA NI (2019). Northern Ireland Climate Change Adaptation Programme 2019-2024.
172. HM Government (2022). *The UK Government's Strategy for International Development.* Foreign, Commonwealth & Development Office.
173. Jones, P. *et al.* (2021). Local Resilience Forums in England. *ATHENS J. Soc. Sci.*, Vol 8, 99–110.