A Horizon Scan of Global Catastrophic Risks

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Abstract

There are a number of global catastrophic risks that have been the subject of interest from the international community. Their scale of impact, and difficulty in preparing for them, suggest urgency around prioritisation. Which risks present the highest priority for research and action, however, is unclear. To help address this, we present a horizon scan of global catastrophic risks, with an emphasis on new or neglected tipping points with cascade potential. In total, 32 academics submitted 96 initial issues, which were then narrowed down to the top 15. Common themes across the top rated issues include cascading failures, interactions between threats, the dangers of using inappropriate methodological tools, and the importance of considering wider sociopolitical contexts when assessing risk. Finally, we outline possible ways to use our findings to develop strategies for prevention, mitigation, and adaptation using robust decision-making tools and deliberative assemblies.

Introduction

We are living in an era of proliferating risks. Our awareness of their interconnections, potential tipping points, and the potential consequences is growing. Global catastrophic risk (GCR) can be defined as the "probability of a loss of 25% of the global population and the severe disruption of global critical systems (such as food) within a given timeframe (years or decades) (Kemp et al., 2022)." However, there are also other related classes of risk that are substantially disruptive without meeting this exact threshold, which can be captured with expanded definitions, e.g. civilisational risk as an umbrella term (*see SI: Table 1. Definitions*).

We cannot adequately understand global risk by studying individual threats in isolation (Undheim T. A., 2023; Cremer & Kemp, 2021). Catastrophic risk involves complex causal pathways and threats are often profoundly interconnected. From COVID-19, which had 7.8 billion cases of infection since 2019 (WHO., 2024), to the risk of climate change threatening the livelihoods of 3.2 to 3.6 billion (Pörtner et al., 2022a), risks are significant and impacts potentially catastrophic, yet we have not collectively addressed these with urgency and clarity. Challenges to risk mitigation include groupthink within disciplines, insufficient consideration of black swans, and the inequities in power, information, and related capacities to address risks faced by those most exposed to them (Undheim T. A., 2023; Yang & Sandberg, 2023). The global majority is therefore faced with constrained capacity to mitigate the risks, yet often bears the severest consequences when disasters strike. This remains the case, despite recommendations from the anticipatory governance literature, emphasising the need for desiloing and transparency for reliable resilience building and prevention (Boyd & Wilson, 2021).

Horizon scanning is an exercise developed for a systematic search for medium to long-term opportunities and threats (Sutherland & Woodroof, 2009), in this case using Delphi-style rounds of expert elicitation. Previous horizon scans in bioengineering, ecology, and dual-use research of concern (Kemp et al., 2020; Sutherland et al., 2022; WHO, 2022) have identified and prioritised key emerging themes. Longitudinal analyses suggest that similar scans have been proven effective in improving group judgement and successfully identifying future prominent issues (Sutherland et al., 2019; Parente & Anderson-Parente, 2011).

A central motivation for this research is that while horizon scanning has been deployed in specific areas of catastrophic risk, such as bioengineering (Kemp et al., 2020), or by the WHO for public health after COVID-19 (WHO, 2022), it has not been broadly applied across the drivers of GCR, or for GCRs specifically rather than global risks broadly construed. For example, the yearly WEF Global Risks Report is a horizon scan, but does not necessarily address the growing body of work in the GCR field or extreme risks. We rectify this with a scan that particularly focused on neglected contributors to GCR, such as risk cascades and the tipping points that could trigger them. This is critical since both impacts and crises regularly amplify each other, spill across systems and borders, and have common causes (Homer-Dixon et al., 2015; Challinor et al., 2018; Keys et al., 2019; Lawrence et al., 2024).

Here, we present the findings of our first GCR horizon scan. The aim of the horizon scan was to identify issues relating to novel, emerging tipping points that could cascade into, or otherwise drive global catastrophic risk. A key secondary goal was to lay foundations for a solution scan that could assist more comprehensive policy making processes combining foresight, robust decision making, and public deliberation (Cremer & Whittlestone, 2022; Kemp et al., 2022; Dal Prá et al., 2023).

Methods

32 expert participants were recruited with varied disciplinary backgrounds, drawing from leading publications, departments, and conferences in a number of fields related to GCR. Diversity in participants was prioritised to ensure a breadth of experience and expertise, crucial determinants of the success of collective intelligence (Yang & Sandberg, 2023).

The participants were asked to submit key tipping points “with cascade potential that contribute to civilisational risk” as relevant issues for scoring, especially those that are new or neglected. Key definitions of terms relevant to the horizon scan provided to the participants in the initial drafting, evaluation, and deliberation process are summarised in *SI: Table 1*.

The initial elicitation emphasised tipping points, in part due to their clear potential for triggering abrupt catastrophic change. However, the pool of submitted issues was ultimately broader, including a wide range of drivers for systemic and catastrophic risk. Since these issues still contribute significantly to the possibility of GCR cascades, they were retained.

The criteria for the selection of these issues were that they were:

- Global in relevance or scope, with the potential to cascade across global systems.
- Emerging, novel, and/or otherwise neglected and deserving of greater research and/or policy attention.

The horizon scanning process followed the Investigate Discuss Estimate and Aggregate (IDEA) Protocol (Hanea et al., 2017) with two adjustments.

First, we included a ‘neglectedness’ metric alongside ‘heard of’. This was done to include issues that had been heard of before, but which still seemed sufficiently urgent to be valuable.

Second, we randomised the order in which issues were presented to participants, reducing the risk of systematic biases due to scoring fatigue. The process is summarised below in *Figure 1*.

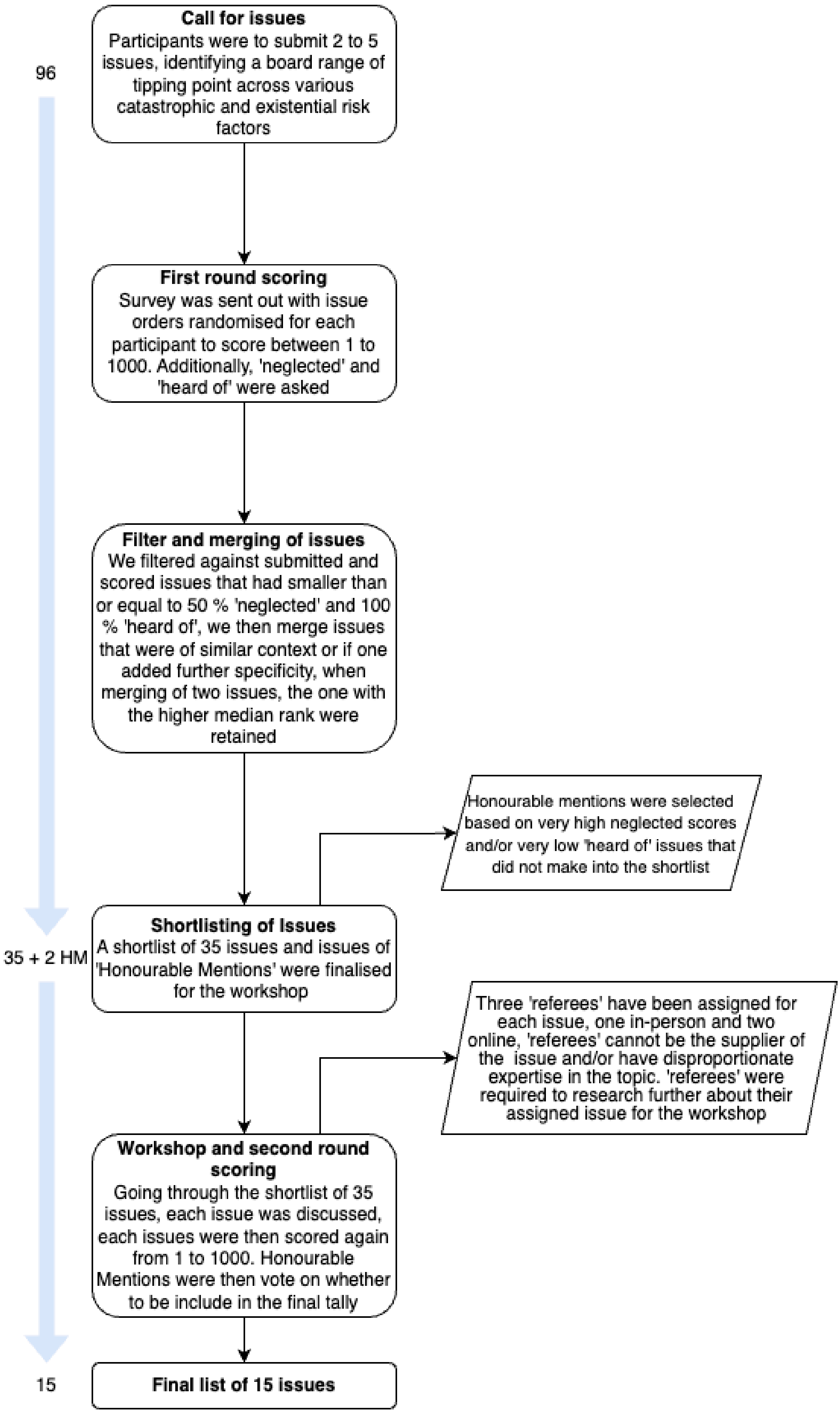

Figure 1. An Overview of the Modified IDEA Protocol

An initial set of 96 issues was submitted by participants. These were then scored anonymously on a scale of 1-1000. We calculated rank scores by ranking each issue within an individual's score sheet and then taking the median rank of an issue across participants (*see SI: Table 2.*). This was to prevent any skewing of the averages that could be caused by scores that deviate significantly from the majority, while ensuring the order of preference for each participant was preserved. The 'neglectedness' and 'heard of' scores were used as a disqualifier for extreme values: issues achieving 50% 'neglected' and below, and 100% 'heard of' were removed. After merging 18 similar issues, we derived an initial shortlist of 37 issues, which also included 2 'honourable mention' issues which did not reach the original top 35 but which had extreme values for very high 'neglectedness' or very low 'heard of' scores.

The process culminated in a deliberative meeting with 25 experts, of which 8 attended in-person and 17 online, with 2 experts contributing commentary without attending on the day. The participants discussed and re-scored the 37 shortlisted issues (again out of 1000, with rank scores calculated as above), with the final top 15 issues being selected as "priority risks".

Results - Priority Risks

The resulting final priority list of 15 top rated issues after deliberation and a final re-scoring are presented below in ascending order of the final rank (*see Table 1.*).

Issue	Issue Categories (Main in bold)	Mean Score	Median Rank	Final Rank
Integration of artificial intelligence in Nuclear Weapons Systems	**Nuclear Weapons**, AI, War & Security	801	3	1
State Capacity Deficits	**Government & Politics**	639	8	2
Cascading failures of global food systems leading to famines	**Food Security**, Climate Environment & Ecology, Systemic Risks	708	8.5	3
Climate change-induced displacement in the context of escalating polycrisis	**Society**, Climate Environment & Ecology	664	10	4
Unclear future of the ocean carbon sink	**Climate Environment & Ecology**	647	10.5	5
Declining Epistemic Robustness	**Epistemics**, AI	575	11	6
Supercharged Surveillance States	**Government & Politics**, AI	653	11.5	7
AI in bioengineering arms races	**Biosecurity**, AI	672	12	8

Collapse of the truth in the age of artificial intelligence	**Epistemics**, AI	611	12	8
Instability and collision of objects in the Earth's orbit	**Space**	594	12	8
Collapse of trade networks due to the destruction of key hubs	**Food Security**, Systemic Risks, Climate Environment & Ecology, War & Security	629	13	11
Political radicalisation & polarisation driven by ecological destabilisation	**Society**, Government & Politics, Climate Environment & Ecology	539	14	12
Large-scale heat stress	**Climate Environment & Ecology**, Food Security	611	15	13
Accelerated development and deployment of Autonomous Weapons Systems (AWS) without adequate oversight	**War & Security**, AI, Government & Politics	547	16	14
Termination Shock from Solar Radiation Management	**Climate Environment & Ecology**	514	17.5	15

Table 1. Score and rank statistics for the 15 identify issues and their main and adjacent categories

Integration of artificial intelligence into Nuclear Weapons Systems

Nuclear risks have existed for most of a century, but the integration of artificial intelligence (AI) into nuclear weapons systems introduces new complexities. Such systems could strengthen nuclear arsenals, optimise decision-making processes, and improve command and control systems (Cox & Williams, 2021). Alternatively, AI could destabilise the nuclear strategic balance in other ways, by changing detection capabilities (Geist & Lohn, 2018) and facilitating autonomous decision-making, leading to accidental or inadvertent conflict escalation (Geist & Lohn, 2018; Johnson J., 2021); it could also negatively affect the psychology of key strategic decision-makers (Payne K., 2018). Autonomous AI systems tasked with monitoring and responding to threats could misinterpret data, engage in unpredictable behaviours, or react autonomously to adversarial attacks, resulting in the initiation of nuclear warfare (Bengio Y., 2023) and its serious negative impacts on, for example, global food security (Xia et al., 2022).

Moreover, integrating AI into nuclear command and control systems could exacerbate the risk of cyberattacks and information warfare (Maas et al., 2023). Malicious actors, including state-sponsored hackers or terrorist organisations, could exploit vulnerabilities in AI algorithms or manipulate data feeds to undermine the reliability of nuclear command systems, leading to disruptions, false alarms, or unauthorised launches (Hoell and Mishra, 2023).

State Capacity Deficits

State capacity is the government's ability to meet their objectives (Vaccaro A., 2023), typically by providing public goods and services, such as transport, education, health and security. This is funded by taxation and other government income. With repeated economic shocks (including the 2008 Global Financial Crisis and Covid-19 pandemic), many of the richest countries saw government spending far outweigh taxation. G7 countries' debt-to-GDP rose from 76.8% in 2010 to 90.4% in 2023 on average, peaking at 94.1% in 2020 (Dyvik E. H., 2024). High debt levels means reduced resources, which, when combined with low trust in governments (OECD., 2024) and reduced political stability (a relative deterioration of which has been seen in high income OECD countries over the past decade) (Kaufmann & Kraay, 2023), contributes to a diminished capacity of states to prevent and mitigate global catastrophic risks (Avin et al., 2018). Reduced state capacity also risks political extremism, nationalism, and weakened international cooperation, affecting the poorest countries and exacerbating inequality (Peters B. G., 2021), with potentially drastically reduced economic and societal stability.

Cascading failures in global food systems leading to famines

The complexity of the global food system is necessary for feeding the world's growing population. It entails production, processing, distribution, and trade of multiple commodities at global scale. This complexity also makes global food systems susceptible to disruptions leading to cascading risks − that is, failure in one part of the food system triggers a domino effect inducing further shocks in related systems (e.g. food, economic, health) across local, regional, and global scales (Burkholz & Schweitzer, 2019). The severity of the resulting impacts could exacerbate the situation of nearly 300 million people already under chronic hunger (WFP., n.d.), and potentially increase this number.

Some likely present-day stressors or disruptive events could include crop failures due to climate change, natural hazards and/or biohazards; supply disruptions arising from conflicts (World Bank, n.d.), export bans, and loss of major food exporters; and the related difficulties with importing and accessing sufficient economical food (Burkholz & Schweitzer, 2019; Kornhuber et al., 2023; Jehn et al., 2024). These events build upon other constraints and have feedback with other issues, such as wars, or the loss of critical infrastructure due to e.g. flooding in major ports.

Climate change-induced displacement in the context of escalating polycrisis

Displacement is a forced or involuntary, reactive movement of people between places. This can be short-term or long-term, and can occur within, or between, nations. While the drivers of displacement are complex, it is clear that climate change and other environmental pressures have the potential to lead to displacement on a vast scale: even “moderate” warming of 2.7°C will leave one third of the global population outside of the historical human climate niche (Lenton et al., 2023), and the number of people living in low-elevation coastal areas vulnerable to sea level rise will surpass 1 billion this century (Hauer et al., 2020). As with many climate risks, this risk is unevenly distributed. Climate-change-driven displacement would interact with a simultaneous and mutually reinforcing web of crises and shocks (Spaiser et al., 2023), such as domestic or international conflicts, (climate change-induced) food insecurity (as in multiple food security issues in this scan), radicalisation (as in the ‘Political radicalisation & polarisation driven by ecological destabilisation’ issue below), financial crisis (e.g. triggered by loss of asset and property value due to natural disasters and increasing retreat of insurers) and so on. With societies overwhelmed by multiple interacting crises and hence increasingly depleted of capacities (as in the ‘State Capacity Deficits’ issue above) to solve problems through cooperation, ecological and social destabilisation could continue unstopped, leading to further or sequential displacement, harming hundreds of millions of people, and contributing to other global catastrophic risks.

Unclear future of the ocean carbon sink

The ocean regulates Earth's atmosphere and climate by not only generating much of Earth's oxygen, but also absorbing and storing vast amounts of carbon dioxide (CO_2), and taking up excess heat from anthropogenic emissions. From the 1960s to the late 2010s, the ocean has absorbed 25 ± 2% of anthropogenic CO_2 emissions and 90% of excess heat (Gruber et al., 2023). However, model projections indicate this absorption capacity will decline in future (Canadell et al., 2021), and may be more sensitive to climate change than expected (Gruber et al., 2023).

In tandem with the onset stages of the El Niño, the year 2023 marked an off-the-charts sea surface temperature anomaly in the North Atlantic, which was 1.36°C above the average of 1991-2020 (ECMWF Copernicus, 2023). The net ocean carbon uptake is likely decreasing due to the following three reasons: First, reduced CO_2 storage capacities arise from increased ocean acidification; Second, enhanced CO_2 outgassing can be expected from ocean warming and changes in ocean circulation and biology; Third, due to emission reductions and subsequently reduced atmospheric CO_2 growth rates, net ocean carbon uptake rates will suffer (Gruber et al., 2023).

If the capacity of oceans to absorb carbon is reduced into the far future, this could result in greatly reduced global environmental resilience for example, through drastically modified marine food webs subverting food security, and extreme temperatures and droughts in regions such as in the Pacific. Moreover, a lock-in of self-amplified warming could occur. The known consequences of such a change include sea level rise, increased intensity of extreme events, and shifts in climate patterns leaving ecosystems mal-adapted and the loss of the human climate niche (Lenton et al., 2023).

Declining Epistemic Robustness

The erosion of decision-making processes constitutes a risk factor across all GCRs (Seger E., 2023). Epistemic robustness, i.e. epistemic processes that can absorb disturbances, requires that decision-makers have accurate information and uncertainty estimates (Faber M., 2011). Numerous factors, however, can make epistemic robustness difficult and erode decision-making quality, including inadequate education (Cokely et al., 2018), ideological biases (Ruisch & Stern, 2021), and poor mental health (NIMH., 2023). While not a new phenomenon, evidence suggests that vulnerability, exposure, and attacks on epistemic robustness are facilitated through digital media and highly connected networks (e.g. Ecker et al., 2022, Singer & Brooking, 2018; Benkler et al., 2018; Bond et al., 2012). Part of the problem is that there are financial and political incentives to spread disinformation and that there is a lack of data about the direct consequences (and only rarely access to platforms to study the effects). Digital tools to produce and disseminate misleading content are becoming cheaper and more accessible, which can increase the scale and profitability of influence campaigns (Herasimenka et al., 2023; Goldstein et al., 2023; Brewster J., 2024). Effectively addressing any GCR will require novel forms of human coordination. That in turn requires effective information processing by the collective. We need to monitor this and know when it is failing.

Supercharged Surveillance States

There is increasing evidence suggesting that democracy is declining globally (Nord et al., 2024). This trend coincides with the rise of increasingly sophisticated technologies for surveillance and social control, such as the combination of drones with facial recognition algorithms, or multiple data streams with machine learning. These surveillance methods are aided by new sources of data, including DNA databases, biometric data, and social media (Garcia D., 2017). The intrusiveness of surveillance tools can be masked through the conveniences they provide. In some cases, either due to convenience or ignorance, people provide their data willingly (Troullinou P., 2017). The increasing use of these interconnecting technologies may push societies into lock-in scenarios of supercharged surveillance regimes, dominated by entrenched states and/or companies. Controlled publics have diminished agency (McGarth J., 2012), as their range of actions and responses are restricted, which can make them more vulnerable and less capable of responding to extraordinary scenarios and crises.

AI in bioengineering arms races

Advancements in artificial intelligence have undeniably propelled significant strides in the life sciences arena. However, a pressing concern exists regarding the potential misuse and weaponisation of biological agents facilitated by AI (Matthews et al., 2024). The concern is twofold: AI’s capacity to first remove existing barriers to misuse, and second to enable more advanced biological weapon development.

While current systems “provide at most a mild uplift” to capabilities, (Patwardhan et al., 2024) and “did not measurably change the operational risk” (Mouton et al., 2024), this seems likely to change as the tools are made to be more powerful. Unlike generative AI, which uses natural language processing, AI-based BDTs are designed to manipulate biological data to create proteins, viral vectors, and potentially other biological agents (Vindman et al., 2024). Previously, the synthesis of viruses was confined to a select few elite scientists in advanced laboratories. However, the proliferation of AI has further expanded this capability to an estimated 30,000 individuals with the requisite talent, training, and technological access (Field M., 2024). If such weapons are developed, there may be a temptation to use them in combat scenarios, it may be easier to launch AI-developed biological weapons than military personnel. This may also lead to unstable mutually assured destruction concerns that an adversary will launch first.

Addressing these concerns necessitates a comprehensive approach encompassing robust oversight, with initial efforts taking place with the International Biosecurity & Biosafety Initiative for Science promoting screening of DNA synthesis orders, stringent oversight mechanisms to enforce the biological weapons convention in light of the new risks, and continued international collaboration and technical research on methods to mitigate the risks posed by AI-facilitated creation and misuse of biological weapons via “enabling language models to better distinguish between harmful and harmless uses of biology” (Anthropic, 2023). Further initiatives such as the iGEM Foundation are working to embed ethics and risk into the synthetic biology community globally. But failure to address these challenges promptly and effectively could have dire consequences for global security and stability.

Collapse of the truth in the age of artificial intelligence

The distinction between true and fake news, pictures, videos, or emotions has been under pressure in recent decades. This trend has accelerated with the growing ability of (generative) artificial intelligence systems, including large language models and AI-generated fake voice, images, and videos. In combination, these continue to degrade society’s ability to differentiate fact from fiction, with lasting impacts for individuals and companies (e.g. Chen & Magramo, 2024).

This epistemic degradation of “informed ignorance” despite availability of information (Cohen & Garasic, 2024) comes alongside political polarisation on social media, the ability for political and other actors to lie at scale, and the asymmetric costs of creating versus debunking fiction, so that society’s memetic infrastructure is fragile and breaking. At the same time, fiction may spread faster than truth, and be hard to debunk due to echo chambering, leading to vicious cycles (Baumann et al., 2020).

Truth decay (Kavanaugh & Rich, 2018) will not independently imperil society, but may curtail the engines of growth and prosperity, as well as severely limit its ability to respond to other threats (e.g. climate misinformation) in light of confusing facts with fakes (Galaz et al., 2023). In particular, it threatens political systems that are based on the rule of many (e.g. democracies) (Kreps & Kriner, 2023).

Instability and collision of objects in the Earth’s orbit

The proliferation of Earth-orbiting satellites, exemplified by megaconstellations like SpaceX's Starlink, poses catastrophic risks for the Earth's environment and communications technology. Firstly, the accumulation of satellites raises concerns about the Kessler Syndrome, where collisions generate space debris faster than it decays (Kessler D. J., 2000). The tipping point would be when there is such density of objects in orbit, that a collision sets off a self-sustaining cascade of collisions, rendering low earth orbit unsafe for satellites. This would threaten modern communication technology, GPS, Earth observation, and global communications systems. The loss of satellite-based hazard monitoring and early warning systems could increase the uncertainty, as well as the unaffordability of insurance in at-risk areas, contributing to an riskier and uninsurable future (Eberle & Sebesvari, 2023). Secondly, as defunct satellites drop from orbit, they burn up in the lower atmosphere, leaving conductive, electrically charged particles. The resultant layer of conductive particles can accelerate the weakening of the Earth’s magnetic field (ESA., 2020) and exacerbate ozone depletion, leaving humanity vulnerable to solar storms and radiation. This, in turn, could lead to mounting health costs and disruptions to electrical infrastructure. Urgent action, including regulations and responsible spacefaring practices, is crucial to avoid these catastrophic risks and preserve our orbital infrastructure and environmental monitoring capabilities.

Collapse of trade networks due to the destruction of key hubs

International trade has become of utmost importance for the global economy, as just-in-time services and interconnected global supply chains proliferate. Today, almost all sectors are reliant upon quick and responsive flows of inputs and outputs, due to the pressure to reduce costs and the increasing complexity of global production (Baldwin R., 2013).

The impact of COVID-19, Russia’s invasion of Ukraine and the disruption of shipping through the Red Sea by Houthi attacks have highlighted the risk of trade disruptions. Governments are starting to take notice (Baldwin & Freeman, 2022), however, the global economy remains exposed, and these scenarios were far from the worst case.

Potential triggers for a larger, catastrophic trade disruption include volcanic eruptions crippling vital infrastructure in global “pinch points” (Mani et al., 2021), severe pandemics, natural disasters or conflict (Jehn et al., 2024). Simultaneously disrupting one or more central global trade hubs could seriously impair the functioning of vital sectors, as the loss of a few key inputs can cripple complex manufacturing supply chains. This could impact the response to the original disaster, and there is a risk that a large trade disruption would lead to a cascade: as the output of critical goods fall, export bans are introduced and conflicts over access rise, creating further trade disruptions (Farrell & Newman, 2022).

Political radicalisation & polarisation driven by ecological destabilisation

Exposure to ecological threats can push people towards more authoritarian views (Fritsche et al., 2012, Spaiser et al., 2024). On the other hand if people feel climate mitigation measures threaten their way of life, they can become more radicalised as well. Such tendencies are amplified in societies with stark inequalities and high political polarisation (Stewart et al., 2020). Radicalisation of societies in response to escalating climate change and breaching of planetary boundaries, has also been observed in the Global South (Rahman et al., 2022).

Such radicalisation processes could become self-reinforcing: rising right-wing and authoritarian ideology makes it harder to address environmental issues (Czarnek et al., 2021), leading to a higher number and more damaging ecological threats. This, in turn, pushes people to become more authoritarian. This self-reinforcing cycle could also exhibit a tipping dynamic, and recovery to a more cooperative state would become increasingly difficult. These dynamics could lead to the rise of currently fringe political ideologies, such as ecofascism (Campion K., 2023), which reinterprets white supremacist ideology in the context of the climate crisis, i.e. states embracing such ideologies would seek to secure access to shrinking human climate niches and resource pools for their populations at all costs. International efforts to combat critical global issues would break down if powerful nations or groups of nations become radicalised, which could further fuel global destabilisation.

Large-scale heat stress

High temperatures and humidity commonly defined by wet bulb temperature > 35°C cause extreme heat stress in humans with severe impacts on wellbeing, physical and mental health (e.g. through neurological damage), and eventually increased mortality (Vecellio et al., 2023; Aldern C. P., 2024). Already at moderate levels of global warming (+2 to +3°C), the threshold for extreme heat stress will be exceeded during large parts of the year across much of the tropics, which are presently home to about half of humanity (Masuda et al., 2024). Besides direct health impacts, most economic activity takes place outdoors in these regions and will consequently be impaired, causing substantial economic loss and exacerbating biophysical losses in food production (Kummu et al., 2021; Masuda et al., 2024). This may lead to compound and cascading failures of social, economic, and food systems in hotspots, which can spill across the region and over to others via mass displacement, conflict, and supply chain disruptions (Lenton et al., 2023) provided that at present the tropics are also a hotspot of fragile states (Kemp et al., 2022) and mostly have low climate resilience (Kummu et al., 2021). These severe heat impacts will be compounded by sea level rise and recurrent floods for which the tropics are as well the projected hotspot with most vulnerable populations (Hauer et al., 2020). This renders climate change impacts in the tropics a likely starting point for an existential socio-economic tipping cascade triggered by global warming.

Accelerated development and deployment of Autonomous Weapons Systems (AWS) without adequate oversight

Over 85 militaries have autonomous weapons system (AWS) programmes, and drones and robotic systems capable of lethal force are being integrated into national defence inventories and deployed in ongoing conflicts (Hambling D., 2023). There is no international regulatory framework on the deployment of these AWS technologies, which has undermined international law protections. AWS have effectively blurred the boundaries as to when nations are at war, the spatial boundaries of military operations, and prevent transparency with regards to compliance to just war theory (Strachan H., 2013). This continues the trend set by cyber warfare, but AWS are significantly more disruptive to international norms because they have direct physical effects. Their relative cheapness, operational opacity, and the way they negate the need for “boots on the ground” means that they are more readily deployed by military and political chains of command. Current rapid proliferation means that non-state actors and terrorist organisations are also already starting to use these capabilities (see Delhi Declaration on countering the use of new and emerging technologies for terrorist purposes). The strategic effects of AWS, ease of catalysing escalation of conflict unchecked and implications on geopolitical stability represent a critical transition in theory of war (Luce E., 2021).

Termination Shock from Solar Radiation Management

One proposed solution to climate change risk is solar geoengineering: reflecting solar energy back into space to cool the Earth. The cheapest option is stratospheric aerosol injection (SAI): injecting particles into the atmosphere which reflect sunlight (Smith W., 2020). Solar geoengineering does not change the amount of greenhouse gases in the atmosphere and aerosols only have a half-life of 8 months (Parker & Irvine, 2018). Hence stopping any scheme would result in renewed, rapid global heating. The rate of warming matters and a temperature rise of multiple degrees over decades could be catastrophic. This effect is known as termination shock. Termination shock could occur due to either intentional deactivation or being knocked offline by a disaster.

The risk may seem minimal since an SAI system would cost less than 1 % of the GDP of the G20 to reactivate and could be made resilient to natural disasters and terrorist attacks (Parker & Irvine, 2018). Unfortunately, governments often don’t act rationally during crises and an extreme disaster such as a nuclear war or a solar flare could disable even a robust system (Baum et al., 2013). Hence, solar geoengineering doesn’t eliminate climate risk. Instead, it creates latent risk and shifts the distribution of risk, making the average outcome safer while making the worst-case more extreme (Tang & Kemp, 2021).

Results - Deliberation and opinion shifts

Numerous studies suggest that deliberation can change minds and improve judgement (Steenbergen et al., 2003; Luskin et al., 2014). We found evidence for this in the horizon scan. To assess the impact of deliberation during the horizon scan workshop, we classified the 35 issues along with the 2 honourable mentions into twelve main themes and monitored the score change before and after the workshop (*see Table 1.; Figure 2.*). We employed a slightly modified weighted least square, where the weights were allocated based on the variance rather than the reciprocal of the variance within each classification. This allows us to take into consideration anomalous scores that deviated above or below the averages.

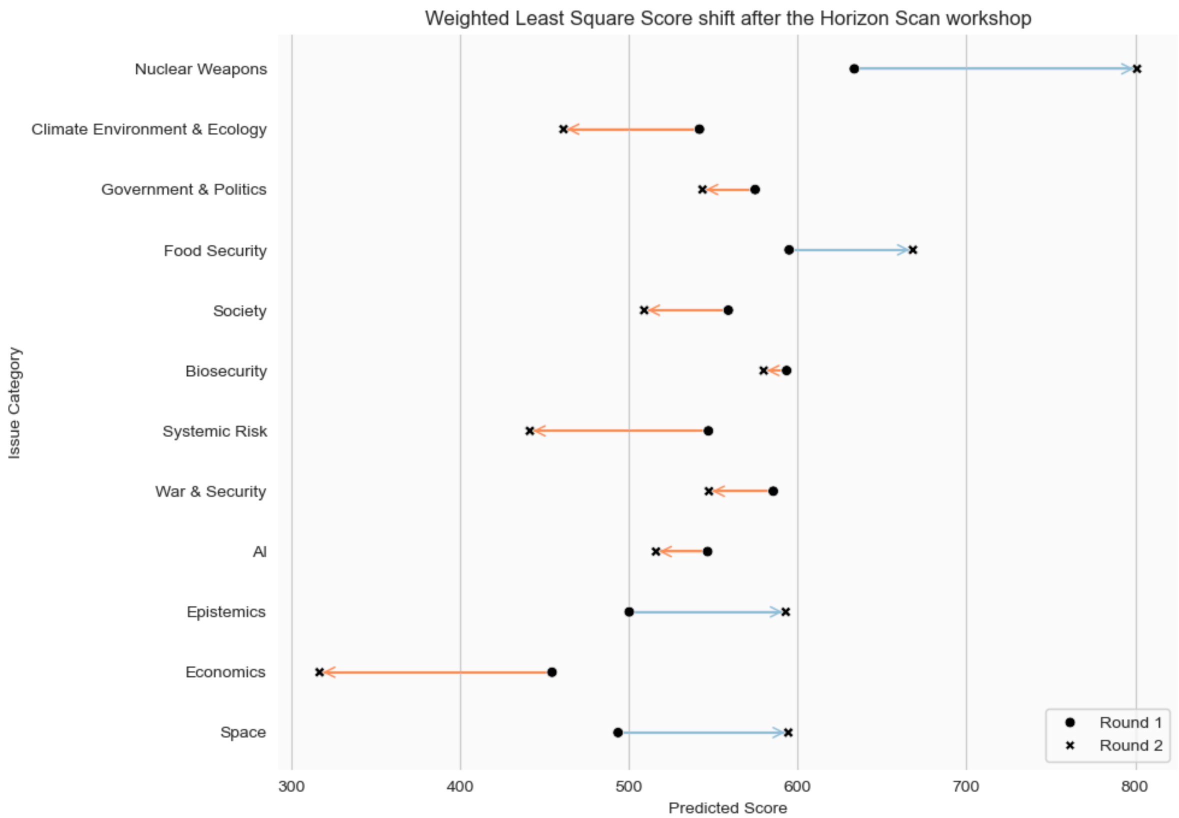

Figure 2. An overview of the impact of deliberation on scoring for the 37 issues' categories. The changes in scoring of issues aggregated before and after the horizon scan workshop, where orange lines indicate a decrease in the predicted score after the deliberation and sky blue lines indicate an increase in the predicted score. Issue categorisation for the WLS regression uses the main category domain we think they fall in. A large portion of issues are at the intersection of two (occasionally three) themes. The classification is a simplified attempt that allows quantification of results (see Table 1.) for the multi-classification and the interconnectedness of the above issues.

Discussion

The resulting issues span a wide variety of discipline and specificity. Many of these issues are found to be interconnected, with a few sharing common drivers (*see Figure 3.*) which made analysis of the cause, consequences, and mitigation of the identified risks complex. For instance, five centre on the development and application of AI systems and six on climate change. Several issues are causally connected to institutional failures or deficits, or could cascade together. Hence, a key future step will be trying to map these issues together to create a more complete picture of global catastrophic risk (Kemp L., 2024).

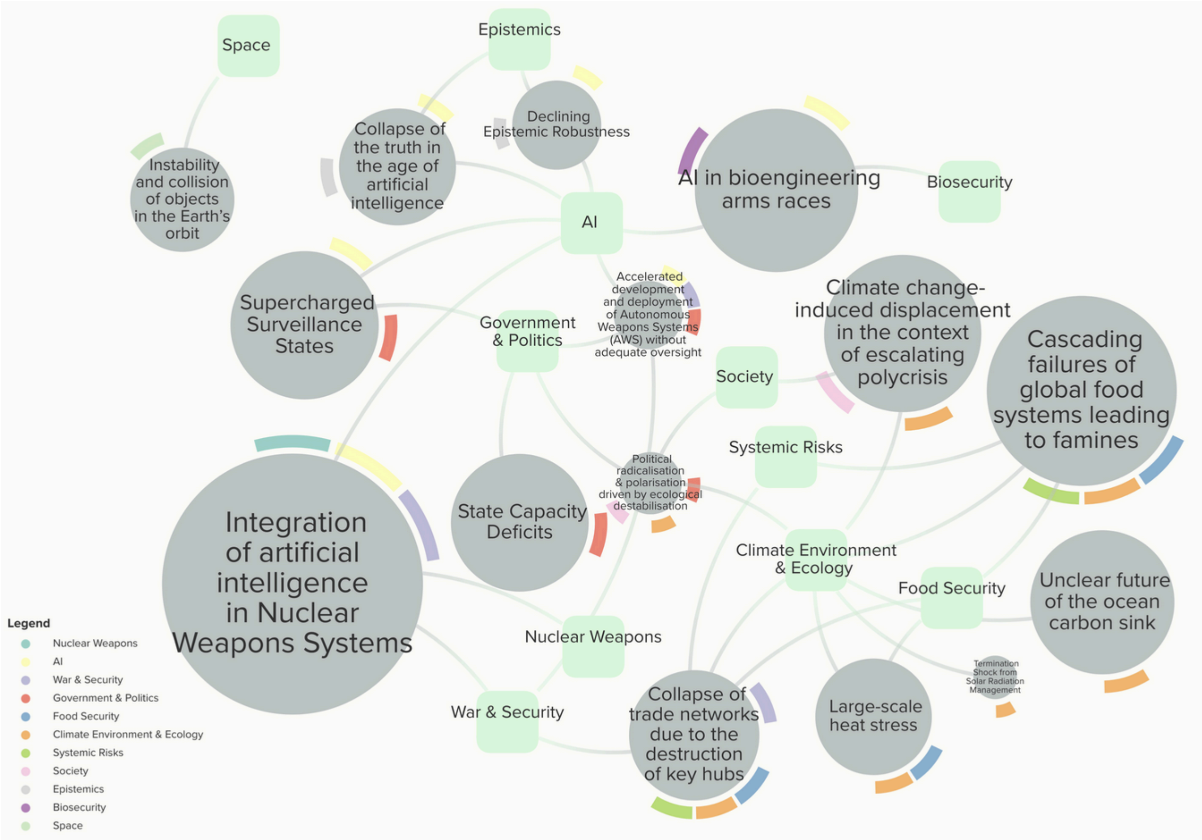

Figure 3. Top 15 issues categorisation and their interrelatedness to one another. Size of shape reflects the mean score, colours are issue categories.

Poor responses to escalating dynamics such as political radicalisation, polarisation, and authoritarianism, were consistently highlighted. The rise of political radicalisation was one prominent example, while the creation of supercharged surveillance states could be a 'stomp reflex' reaction (Cremer & Kemp, 2021) to future crises. Future foresight in the area should pay close attention to response risk and its ability to snowball into negative social tipping points (Lenton et al., 2023).

Food security featured prominently across issues. It was both central to issues such as cascading regime shifts and the collapse of trade networks (Jehn et al., 2024), threats such as nuclear winter, extreme climate risk scenarios, and appeared in the background discussions of many others. This is partly due to the interconnected, concentrated (Clapp J., 2022), and fragile state of industrial agriculture (Moersdorf et al., 2023).

Participants also recognised the limitations of current approaches to addressing these risks, recurrently noting the lack of appropriate tools for comprehending catastrophic risks. Even in relatively well-researched and developed risk areas such as climate risk models usually do not properly consider tail-risk, risk cascades and interactions, or adequately incorporate tipping points. Either using more appropriate tools such as exploratory scenario modelling as in decision making under deep uncertainty (which allows for several possible outcomes, including worst case scenarios, to be mapped with relevant trade offs identified (Marchau et al., 2019; Workman et al., 2020), using storylines to make risks more concrete (Shepherd et al., 2018) is necessary.

Participants expressed a desire for moving beyond identification of risks to exploring how to mitigate these risks. Crafting legitimate and effective policy for such complex issues will likely require the combination of foresight with deliberative democratic measures (e.g. citizens' assemblies), targeting comprehensive and nuanced recommendations coproduced with those exposed to them (Cremer and Whittlestone, 2021; Kemp et al., 2022; Dal Prá et al., 2023; Kemp L., 2024). Such approaches could build on this horizon scan.

Despite these achievements, the horizon scan has suggested several ideas for future work. First, the deliberations were reflective of individual expertise and did not involve more comprehensive measures such as a systematic literature review. There was considerable sensitivity to the sample of participants, with some issues (such as food security) potentially reflecting a strong contingent of researchers in this sample. Future scans could feed in a summary of different lines of evidence to better informed deliberations. Second, as noted above, the scan also did not fully consider the interconnections across issues, including their mitigation. Finally, although we were conscious of including diverse demographics with participants invited to ensure a breadth of career seniority levels, locations, genders, and domain specialties, this was not as successful as would have been desired. To ensure more optimal collective intelligence, future horizon scans would benefit from a more systematic sampling of invited participants to improve the gender and geographic balance especially.

The issues in this horizon scan covered a broad variety of topics with the contribution of diverse experts through a deliberation exercise to reach broad consensus. We would like to emphasise that existential and catastrophic scale trends that could pose civilisational risks arise in particular if various issues co-occur, interact, and reinforce each other.

Planetary-scale processes such as climate change and breaching of various planetary boundaries increase the likelihood for such co-occurrences and interactions as they typically impact various systems simultaneously (Lade et al., 2020; Richardson et al., 2023). Similarly transformative technologies such as AI that are likely to be adopted across the globe and across sectors simultaneously, could also lead to co-occurrence and interactions of risks, shocks, and crises. Moreover, many risks escalate to catastrophic levels only when institutions fail, linking many of the issues discussed here to the issue of state capacity deficits, which itself however is linked to various issues that increasingly overwhelm and undermine capacities of states and international institutions.

Conclusion

This exercise will hopefully provide a foundation to guide broad multidisciplinary and discussion on future catastrophic risk research and management, informing further exploration of risk management strategies and associated policy formulation. Subsequently, an important question will be how societies can strengthen institutional capacity to deal with multiple crises and shocks. We suggest that future work in this area could entail:

1. Systems mapping around the relevant tipping points in each issue. For example, two to three of the highest ranked issues could be mapped to elucidate further their origins, drivers, and interventions.
2. Exploratory modelling exercises, such as those in decision making under deep uncertainty (Marchau et al., 2019) to identify particularly tractable options for multiple and cascading risk mitigation.

3. A solution scan for specific issues. This would build on the preparatory work above, but address explicitly what the public and policymakers can reasonably do to build resilience at scale.
4. Finally, a public deliberation in the form of a citizen assembly, that would enable the emergence of democratic consensus on developing societal resilience at the local level and at scale. This would likely come last, to ensure it is enriched fully with the prior steps.

Systems mapping and exploratory modelling would constitute focused preparations for subsequent solution scanning and public deliberation, with the former modelling exercise to systematically inform the latter collective intelligence component, targeting broad-based consensus toward policy recommendations for civilisational risks.

Bibliography

Aldern, Clayton Page. '"Everybody Has a Breaking Point": How the Climate Crisis Affects Our Brains'. *The Guardian*, 27 Mar. 2024. *The Guardian*, https://www.theguardian.com/environment/2024/mar/27/everybody-has-a-breaking-point-how-the-climate-crisis-affects-our-brains.

Anthropic. *Frontier Threats Red Teaming for AI Safety*. https://www.anthropic.com/news/frontier-threats-red-teaming-for-ai-safety. Accessed 16 July 2024.

Avin, Shahar, et al. 'Classifying Global Catastrophic Risks'. *Futures*, vol. 102, Sept. 2018, pp. 20–26. *ScienceDirect*, https://doi.org/10.1016/j.futures.2018.02.001.

Baldwin, Richard. 'Global Supply Chains: Why They Emerged, Why They Matter, and Where They Are Going'. *Global Value Chains in a Changing World*, WTO iLibrary, 2013, pp. 13–59. *www.wto-ilibrary.org*, https://doi.org/10.30875/3c1b338a-en.

Baldwin, Richard, and Rebecca Freeman. 'Risks and Global Supply Chains: What We Know and What We Need to Know'. *Annual Review of Economics*, vol. 14, no. Volume 14, 2022, Aug. 2022, pp. 153–80. *www.annualreviews.org*, https://doi.org/10.1146/annurev-economics-051420-113737.

Baum, Seth D., et al. 'Double Catastrophe: Intermittent Stratospheric Geoengineering Induced by Societal Collapse'. *Environment Systems & Decisions*, vol. 33, no. 1, Mar. 2013, pp. 168–80. *Springer Link*, https://doi.org/10.1007/s10669-012-9429-y.

Baumann, Fabian, et al. 'Modeling Echo Chambers and Polarization Dynamics in Social Networks'. *Physical Review Letters*, vol. 124, no. 4, Jan. 2020, p. 048301. *APS*, https://doi.org/10.1103/PhysRevLett.124.048301.

Bengio, Yoshua. 'AI and Catastrophic Risk'. *Journal of Democracy*, vol. 34, no. 4, 2023, pp. 111–21.

Benkler, Yochai, et al. *Network Propaganda: Manipulation, Disinformation, and Radicalization in American Politics*. Oxford University Press, 2018.

Berrang-Ford, Lea, et al. 'Tracking Global Climate Change Adaptation among Governments'. *Nature Climate Change*, vol. 9, no. 6, June 2019, pp. 440–49. *www.nature.com*, https://doi.org/10.1038/s41558-019-0490-0.

Bond, Robert M., et al. 'A 61-Million-Person Experiment in Social Influence and Political Mobilization'. *Nature*, vol. 489, no. 7415, Sept. 2012, pp. 295–98. *www.nature.com*, https://doi.org/10.1038/nature11421.

Boyd, Matt, and Nick Wilson. 'Anticipatory Governance for Preventing and Mitigating Catastrophic and Existential Risks'. *Policy Quarterly*, vol. 17, no. 4, 2021, pp. 20–31.

Brewster, Jack. 'Essay | How I Built an AI-Powered, Self-Running Propaganda Machine for $105'. *How I Built an AI-Powered, Self-Running Propaganda Machine for $105*, 12 Apr. 2024, https://www.wsj.com/politics/how-i-built-an-ai-powered-self-running-propaganda-machine-for-105-e9888705.

Burkholz, Rebekka, and Frank Schweitzer. 'International Crop Trade Networks: The Impact of Shocks and Cascades'. *Environmental Research Letters*, vol. 14, no. 11, Oct. 2019, p. 114013. *Institute of Physics*, https://doi.org/10.1088/1748-9326/ab4864.

Campion, Kristy. 'Defining Ecofascism: Historical Foundations and Contemporary Interpretations in the Extreme Right'. *Terrorism and Political Violence*, vol. 35, no. 4, May 2023, pp. 926–44. *Taylor and Francis+NEJM*, https://doi.org/10.1080/09546553.2021.1987895.

Canadell, Josep G., et al. 'Intergovernmental Panel on Climate Change (IPCC). Global Carbon and Other Biogeochemical Cycles and Feedbacks'. *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*, Cambridge University Press, 2021, pp. 673–816.

Challinor, Andy J., et al. 'Transmission of Climate Risks across Sectors and Borders'. *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences*, vol. 376, no. 2121, Apr. 2018, p. 20170301. *royalsocietypublishing.org (Atypon)*, https://doi.org/10.1098/rsta.2017.0301.

Chen, Heather, and Kathleen Magramo. 'Finance Worker Pays out $25 Million after Video Call with Deepfake "Chief Financial Officer"'. *CNN*, 4 Feb. 2024, https://www.cnn.com/2024/02/04/asia/deepfake-cfo-scam-hong-kong-intl-hnk/index.html.

Clapp, Jennifer. 'Concentration and Crises: Exploring the Deep Roots of Vulnerability in the Global Industrial Food System'. *The Journal of Peasant Studies*, Jan. 2023. world, *www.tandfonline.com*, https://www.tandfonline.com/doi/abs/10.1080/03066150.2022.2129013.

Cohen, Noa, and Mirko Daniel Garasic. 'Informed Ignorance as a Form of Epistemic Injustice'. *Philosophies*, vol. 9, no. 3, 3, June 2024, p. 59. *www.mdpi.com*, https://doi.org/10.3390/philosophies9030059.

Cokely, Edward T., et al. 'Skilled Decision Theory: From Intelligence to Numeracy and Expertise'. *The Cambridge Handbook of Expertise and Expert Performance*, Cambridge University Press, 2018, p. 476.

Cox, Jessica, and Heather Williams. 'The Unavoidable Technology: How Artificial Intelligence Can Strengthen Nuclear Stability'. *The Washington Quarterly*, vol. 44, no. 1, Jan. 2021, pp. 69–85. *Taylor and Francis+NEJM*, https://doi.org/10.1080/0163660X.2021.1893019.

Cremer, Carla Zoe, and Luke Kemp. *Democratising Risk: In Search of a Methodology to Study Existential Risk*. arXiv:2201.11214, arXiv, 27 Dec. 2021. *arXiv.org*, https://doi.org/10.48550/arXiv.2201.11214.

Cremer, Carla Zoe, and Jess Whittlestone. *Artificial Canaries: Early Warning Signs for Anticipatory and Democratic Governance of AI*. Mar. 2021. *reunir.unir.net*, https://doi.org/10.9781/ijimai.2021.02.011.

Czarnek, Gabriela, et al. 'Right-Wing Ideology Reduces the Effects of Education on Climate Change Beliefs in More Developed Countries'. *Nature Climate Change*, vol. 11, no. 1, Jan. 2021, pp. 9–13. *www.nature.com*, https://doi.org/10.1038/s41558-020-00930-6.

Dal Prá, Giuseppe, et al. *The Odyssean Process*. Odyssean Institute, 23 Nov. 2023. *ResearchGate*, https://doi.org/10.13140/RG.2.2.21281.58720.

Dyvik, Einar H. 'Government Net Debt of G7 Countries as Share of GDP from 2010 to 2023, by Country'. *Government Net Debt of G7 Countries as Share of GDP from 2010 to 2023, by Country*, 4 July 2024, https://www.statista.com/statistics/1370943/g7-government-net-debt-share-gdp/.

Eberle, Caitlyn, and Zita Sebesvari. *Technical Report: Space Debris*. Research report, UNU-EHS, 25 Oct. 2023. *collections.unu.edu*, https://collections.unu.edu/view/UNU:9298.

Ecker, Ullrich K. H., et al. 'The Psychological Drivers of Misinformation Belief and Its Resistance to Correction'. *Nature Reviews Psychology*, vol. 1, no. 1, Jan. 2022, pp. 13–29. *www.nature.com*, https://doi.org/10.1038/s44159-021-00006-y.

ECMWF Copernicus. *Record-Breaking North Atlantic Ocean Temperatures Contribute to Extreme Marine Heatwaves | Copernicus*. 2023, https://climate.copernicus.eu/record-breaking-north-atlantic-ocean-temperatures-contribute-extreme-marine-heatwaves.

ESA. 'Swarm Probes Weakening of Earth's Magnetic Field'. *Swarm Probes Weakening of Earth's Magnetic Field*, 20 May 2020, https://www.esa.int/Applications/Observing_the_Earth/FutureEO/Swarm/Swarm_probes_weakening_of_Earth_s_magnetic_field.

Faber, M. h. 'On the Governance of Global and Catastrophic Risks'. *International Journal of Risk Assessment and Management*, vol. 15, no. 5–6, Jan. 2011, pp. 400–16. *inderscienceonline.com (Atypon)*, https://doi.org/10.1504/IJRAM.2011.043698.

Farrell, Henry, and Abraham L. Newman. 'Weak Links in Finance and Supply Chains Are Easily Weaponized'. *Nature*, vol. 605, no. 7909, May 2022, pp. 219–22. *www.nature.com*, https://doi.org/10.1038/d41586-022-01254-5.

Field, Matt. 'Could AI Help Bioterrorists Unleash a New Pandemic? A New Study Suggests Not Yet'. *Bulletin of the Atomic Scientists*, 25 Jan. 2024, https://thebulletin.org/2024/01/could-ai-help-bioterrorists-unleash-a-new-pandemic-a-new-study-suggests-not-yet/.

Ford, James D., et al. 'A Systematic Review of Observed Climate Change Adaptation in Developed Nations'. *Climatic Change*, vol. 106, no. 2, May 2011, pp. 327–36. *Springer Link*, https://doi.org/10.1007/s10584-011-0045-5.

Fritsche, Immo, et al. 'Global Warming Is Breeding Social Conflict: The Subtle Impact of Climate Change Threat on Authoritarian Tendencies'. *Journal of Environmental Psychology*, vol. 32, no. 1, Mar. 2012, pp. 1–10. *ScienceDirect*, https://doi.org/10.1016/j.jenvp.2011.10.002.

Galaz, Victor, et al. *AI Could Create a Perfect Storm of Climate Misinformation*. arXiv:2306.12807, arXiv, 26 June 2023. *arXiv.org*, https://doi.org/10.48550/arXiv.2306.12807.

Garcia, David. 'Leaking Privacy and Shadow Profiles in Online Social Networks'. *Science Advances*, vol. 3, no. 8, Aug. 2017, p. e1701172. *science.org (Atypon)*, https://doi.org/10.1126/sciadv.1701172.

Geist, Edward, and Andrew J. Lohn. *How Might Artificial Intelligence Affect the Risk of Nuclear War?* RAND Corporation, 24 Apr. 2018. *www.rand.org*, https://www.rand.org/pubs/perspectives/PE296.html.

Goldstein, Josh A., et al. *Generative Language Models and Automated Influence Operations: Emerging Threats and Potential Mitigations*. arXiv:2301.04246, arXiv, 10 Jan. 2023. *arXiv.org*, https://doi.org/10.48550/arXiv.2301.04246.

Gruber, Nicolas, et al. 'Trends and Variability in the Ocean Carbon Sink'. *Nature Reviews Earth & Environment*, vol. 4, no. 2, Feb. 2023, pp. 119–34. *www.nature.com*, https://doi.org/10.1038/s43017-022-00381-x.

Hale, T., et al. *Variation in Government Responses to COVID-19*. 2020. *ora.ox.ac.uk*, https://ora.ox.ac.uk/objects/uuid:0ab73a02-ca18-4e1f-a41b-cfeea2d30e81.

Hale, Thomas, et al. 'A Global Panel Database of Pandemic Policies (Oxford COVID-19 Government Response Tracker)'. *Nature Human Behaviour*, vol. 5, no. 4, Apr. 2021, pp. 529–38. *www.nature.com*, https://doi.org/10.1038/s41562-021-01079-8.

Hambling, David. 'Ukrainian AI Attack Drones May Be Killing without Human Oversight'. *Ukrainian AI Attack Drones May Be Killing without Human Oversight*, 13 Oct. 2023, https://www.newscientist.com/article/2397389-ukrainian-ai-attack-drones-may-be-killing-without-human-oversight/.

Hanea, A. M., et al. 'I Nvestigate D Iscuss E Stimate A Ggregate for Structured Expert Judgement'. *International Journal of Forecasting*, vol. 33, no. 1, Jan. 2017, pp. 267–79. *ScienceDirect*, https://doi.org/10.1016/j.ijforecast.2016.02.008.

Hauer, Mathew E., et al. 'Sea-Level Rise and Human Migration'. *Nature Reviews Earth & Environment*, vol. 1, no. 1, Jan. 2020, pp. 28–39. *www.nature.com*, https://doi.org/10.1038/s43017-019-0002-9.

Herasimenka, Aliaksandr, et al. 'The Political Economy of Digital Profiteering: Communication Resource Mobilization by Anti-Vaccination Actors'. *Journal of Communication*, vol. 73, no. 2, Apr. 2023, pp. 126–37. *Silverchair*, https://doi.org/10.1093/joc/jqac043.

Hoell, Maximilian, and Sylvia Mishra. 'Artificial Intelligence in Nuclear Command, Control, and Communications: Implications for the Nuclear Non-Proliferation Treaty'. *The Implications of Emerging Technologies in the Euro-Atlantic Space: Views from the Younger Generation Leaders Network*, edited by Julia Berghofer et al., Springer International Publishing, 2023, pp. 123–42. *Springer Link*, https://doi.org/10.1007/978-3-031-24673-9_8.

Homer-Dixon, Thomas, et al. 'Synchronous Failure: The Emerging Causal Architecture of Global Crisis'. *Ecology and Society*, vol. 20, no. 3, 2015. *JSTOR*, https://www.jstor.org/stable/26270255.

Jehn, Florian Ulrich, et al. *Food Trade Disruption after Global Catastrophes*. June 2024. *eartharxiv.org*, https://eartharxiv.org/repository/view/7339/.

Johnson, James. '"Catalytic Nuclear War" in the Age of Artificial Intelligence & Autonomy: Emerging Military Technology and Escalation Risk between Nuclear-Armed States'. *Journal of Strategic Studies*, vol. 0, no. 0, pp. 1–41. *Taylor and Francis+NEJM*, https://doi.org/10.1080/01402390.2020.1867541.

Kaufmann, Daniel, and Aart Kraay. *Worldwide Governance Indicators*. 2023, www.govindicators.org.

Kavanagh, Jennifer, and Michael D. Rich. *Truth Decay: An Initial Exploration of the Diminishing Role of Facts and Analysis in American Public Life*. RAND Corporation, 15 Jan. 2018. *www.rand.org*, https://www.rand.org/pubs/research_reports/RR2314.html.

Kemp, Luke, Laura Adam, et al. 'Bioengineering Horizon Scan 2020'. *eLife*, edited by Helena Pérez Valle et al., vol. 9, May 2020, p. e54489. *eLife*, https://doi.org/10.7554/eLife.54489.

Kemp, Luke, Chi Xu, et al. 'Climate Endgame: Exploring Catastrophic Climate Change Scenarios'. *Proceedings of the National Academy of Sciences*, vol. 119, no. 34, Aug. 2022, p. e2108146119. *pnas.org (Atypon)*, https://doi.org/10.1073/pnas.2108146119.

Kemp, Luke. 'Foreseeing Extreme Technological Risk'. *Managing Extreme Technological Risk*, WORLD SCIENTIFIC (EUROPE), 2024, pp. 87–108. *worldscientific.com (Atypon)*, https://doi.org/10.1142/9781800614826_0004.

Kessler, Donald J. *Critical Density of Spacecraft in Low Earth Orbit: Using Fragmentation Data to Evaluate the Stability of the Orbital Debris Environment*. Lockheed Martin, 2000.

Keys, Patrick W., et al. 'Anthropocene Risk'. *Nature Sustainability*, vol. 2, no. 8, Aug. 2019, pp. 667–73. *www.nature.com*, https://doi.org/10.1038/s41893-019-0327-x.

Kornhuber, Kai, et al. 'Risks of Synchronized Low Yields Are Underestimated in Climate and Crop Model Projections'. *Nature Communications*, vol. 14, no. 1, July 2023, p. 3528. *www.nature.com*, https://doi.org/10.1038/s41467-023-38906-7.

Kreps, Sarah, and Doug Kriner. 'How AI Threatens Democracy'. *Journal of Democracy*, vol. 34, no. 4, 2023, pp. 122–31.

Kummu, Matti, et al. 'Climate Change Risks Pushing One-Third of Global Food Production Outside the Safe Climatic Space'. *One Earth*, vol. 4, no. 5, May 2021, pp. 720–29. *www.cell.com*, https://doi.org/10.1016/j.oneear.2021.04.017.

Lade, Steven J., et al. 'Human Impacts on Planetary Boundaries Amplified by Earth System Interactions'. *Nature Sustainability*, vol. 3, no. 2, Feb. 2020, pp. 119–28. *www.nature.com*, https://doi.org/10.1038/s41893-019-0454-4.

Lawrence, Michael, et al. 'Global Polycrisis: The Causal Mechanisms of Crisis Entanglement'. *Global Sustainability*, vol. 7, Jan. 2024, p. e6. *Cambridge University Press*, https://doi.org/10.1017/sus.2024.1.

Lenton, Timothy M., Chi Xu, et al. 'Quantifying the Human Cost of Global Warming'. *Nature Sustainability*, vol. 6, no. 10, Oct. 2023, pp. 1237–47. *www.nature.com*, https://doi.org/10.1038/s41893-023-01132-6.

Lenton, Timothy M., David I. Armstrong Mckay, et al. *The Global Tipping Points Report 2023*. report, University of Exeter, 2023. *hal.umontpellier.fr*, https://hal.umontpellier.fr/hal-04548845.

Lenton, Timothy M. 'Tipping Positive Change'. *Philosophical Transactions of the Royal Society B*, vol. 375, no. 1794, 2020, p. 20190123.

Liu, Jia, et al. 'Government Response Measures and Public Trust during the COVID-19 Pandemic: Evidence from Around the World'. *British Journal of Management*, vol. 33, no. 2, 2022, pp. 571–602. *Wiley Online Library*, https://doi.org/10.1111/1467-8551.12577.

Luce, Edward. *US and China Must Heed Kissinger's Stark Warnings*. 4 Nov. 2021, https://www.ft.com/content/8dc78be5-aa5a-4ea0-9692-0641acf27042.

Luskin, Robert C., et al. 'Deliberating across Deep Divides'. *Political Studies*, vol. 62, no. 1, Mar. 2014, pp. 116–35. *SAGE Journals*, https://doi.org/10.1111/j.1467-9248.2012.01005.x.

Maas, Matthijs, et al. 'Military Artificial Intelligence as a Contributor to Global Catastrophic Risk'. *The Era of Global Risk*, Open Book Publishers, 2023, pp. 237–84. *www.openbookpublishers.com*, https://www.openbookpublishers.com/books/10.11647/obp.0336/chapters/10.11647/obp.0336.10.

Mani, Lara, et al. 'Global Catastrophic Risk from Lower Magnitude Volcanic Eruptions'. *Nature Communications*, vol. 12, no. 1, Aug. 2021, p. 4756. *www.nature.com*, https://doi.org/10.1038/s41467-021-25021-8.

Marchau, Vincent A. W. J., et al., editors. *Decision Making under Deep Uncertainty: From Theory to Practice*. Springer Nature, 2019. *library.oapen.org*, https://doi.org/10.1007/978-3-030-05252-2.

Masuda, Yuta J., et al. 'Impacts of Warming on Outdoor Worker Well-Being in the Tropics and Adaptation Options'. *One Earth*, vol. 7, no. 3, Mar. 2024, pp. 382–400. *www.cell.com*, https://doi.org/10.1016/j.oneear.2024.02.001.

Matthews, Luke J., et al. *Plagues, Cyborgs, and Supersoldiers: The Human Domain of War*. RAND Corporation, 2 Jan. 2024. *www.rand.org*, https://www.rand.org/pubs/research_reports/RRA2520-1.html.

McGrath, John. 'Performing Surveillance'. *Routledge Handbook of Surveillance Studies*, Routledge, 2012.

Moersdorf, Jessica, et al. 'The Fragile State of Industrial Agriculture: Estimating Crop Yield Reductions in a Global Catastrophic Infrastructure Loss Scenario'. *Global Challenges*, vol. 8, no. 1, 2024, p. 2300206. *Wiley Online Library*, https://doi.org/10.1002/gch2.202300206.

Mouton, Christopher A., et al. *The Operational Risks of AI in Large-Scale Biological Attacks: Results of a Red-Team Study*. RAND Corporation, 25 Jan. 2024. *www.rand.org*, https://www.rand.org/pubs/research_reports/RRA2977-2.html.

Munson, Seth M., et al. 'Ecosystem Thresholds, Tipping Points, and Critical Transitions'. *New Phytologist*, vol. 218, no. 4, 2018, pp. 1315–17.

National Institute of Mental Health. 'Mental Illness - National Institute of Mental Health (NIMH)'. *Mental Illness - National Institute of Mental Health (NIMH)*, 2023, https://www.nimh.nih.gov/health/statistics/mental-illness.

Nord, Marina, et al. *Democracy Winning and Losing at the Ballot: Democracy Report 2024*. 4774409, 7 Mar. 2024. *Social Science Research Network*, https://doi.org/10.2139/ssrn.4774409.

OECD. 'Trust in Government'. *Trust in Government*, https://www.oecd.org/en/topics/sub-issues/trust-in-government.html. Accessed 16 July 2024.

OpenAI. *Building an Early Warning System for LLM-Aided Biological Threat Creation*. https://openai.com/index/building-an-early-warning-system-for-llm-aided-biological-threat-creation/. Accessed 25 June 2024.

Parente, Rick, and Janet Anderson-Parente. 'A Case Study of Long-Term Delphi Accuracy'. *Technological Forecasting and Social Change*, vol. 78, no. 9, 2011, pp. 1705–11.

Parker, Andy, and Peter J. Irvine. 'The Risk of Termination Shock From Solar Geoengineering'. *Earth's Future*, vol. 6, no. 3, 2018, pp. 456–67. *Wiley Online Library*, https://doi.org/10.1002/2017EF000735.

Patwardhan, Tejal, et al. 'Building an Early Warning System for LLM-Aided Biological Threat Creation'. *Building an Early Warning System for LLM-Aided Biological Threat Creation*, 31 Jan. 2024, https://openai.com/index/building-an-early-warning-system-for-llm-aided-biological-threat-creation/.

Payne, Kenneth. 'Artificial Intelligence: A Revolution in Strategic Affairs?' *Survival*, vol. 60, no. 5, Sept. 2018, pp. 7–32. *Taylor and Francis+NEJM*, https://doi.org/10.1080/00396338.2018.1518374.

Peters, B. Guy. 'Governing in a Time of Global Crises: The Good, the Bad, and the Merely Normal'. *Global Public Policy and Governance*, vol. 1, no. 1, Mar. 2021, pp. 4–19. *Springer Link*, https://doi.org/10.1007/s43508-021-00006-x.

Pörtner, Hans-Otto, Debra C. Roberts, Melinda M. B. Tignor, et al. *Climate Change 2022: Impacts, Adaptation and Vulnerability*. Working Group II Contribution to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change, Intergovernmental Panel on Climate Change, 2022, https://doi.org/10.1017/9781009325844.

Pörtner, Hans-Otto, Debra C. Roberts, Valérie Masson-Delmotte, et al. *The Ocean and Cryosphere in a Changing Climate*. Special Report of the Intergovernmental Panel on Climate Change, Intergovernmental Panel on CLimate Change, 2022, https://doi.org/10.1017/9781009157964.

Rahman, Muhammad Habibur, et al. '"Storm Autocracies": Islands as Natural Experiments'. *Journal of Development Economics*, vol. 159, Nov. 2022, p. 102982. *ScienceDirect*, https://doi.org/10.1016/j.jdeveco.2022.102982.

Richardson, Katherine, et al. 'Earth beyond Six of Nine Planetary Boundaries'. *Science Advances*, vol. 9, no. 37, Sept. 2023, p. eadh2458. *science.org (Atypon)*, https://doi.org/10.1126/sciadv.adh2458.

Ruisch, Benjamin C., and Chadly Stern. 'The Confident Conservative: Ideological Differences in Judgment and Decision-Making Confidence'. *Journal of Experimental Psychology: General*, vol. 150, no. 3, 2021, pp. 527–44. *APA PsycNet*, https://doi.org/10.1037/xge0000898.

Scheffer, Marten, et al. 'Early-Warning Signals for Critical Transitions'. *Nature*, vol. 461, no. 7260, 2009, pp. 53–59.

Seger, Elizabeth. 'Should Epistemic Security Be a Priority GCR Cause Area'. *Intersections, Reinforcements, Cascades*, 2023, pp. 18–37.

Shepherd, Theodore G., et al. ‘Storylines: An Alternative Approach to Representing Uncertainty in Physical Aspects of Climate Change’. *Climatic Change*, vol. 151, no. 3, Dec. 2018, pp. 555–71. *Springer Link*, https://doi.org/10.1007/s10584-018-2317-9.

Singer, Peter Warren, and Emerson T. Brooking. *Likewar: The Weaponization of Social Media*. Houghton Mifflin Harcourt, 2018.

Smith, Wake. ‘The Cost of Stratospheric Aerosol Injection through 2100’. *Environmental Research Letters*, vol. 15, no. 11, Oct. 2020, p. 114004. *Institute of Physics*, https://doi.org/10.1088/1748-9326/aba7e7.

Spaiser, Viktoria, Sirkku Juhola, et al. ‘Negative Social Tipping Dynamics Resulting from and Reinforcing Earth System Destabilisation’. *EGUsphere*, Sept. 2023, pp. 1–29. *egusphere.copernicus.org*, https://doi.org/10.5194/egusphere-2023-1475.

Spaiser, Viktoria, Kris Dunn, et al. ‘The Effects of Communicating Climate Change Threat: Mobilizing Anger and Authoritarian Affect Displacement’. *Environmental Sociology*, vol. 0, no. 0, pp. 1–12. *Taylor and Francis+NEJM*, https://doi.org/10.1080/23251042.2024.2369739.

Steenbergen, Marco R., et al. ‘Measuring Political Deliberation: A Discourse Quality Index’. *Comparative European Politics*, vol. 1, no. 1, Mar. 2003, pp. 21–48. *Springer Link*, https://doi.org/10.1057/palgrave.cep.6110002.

Stewart, Alexander J., et al. ‘Polarization under Rising Inequality and Economic Decline’. *Science Advances*, vol. 6, no. 50, Dec. 2020, p. eabd4201. *science.org (Atypon)*, https://doi.org/10.1126/sciadv.abd4201.

Strachan, Hew. *The Direction of War: Contemporary Strategy in Historical Perspective*. Cambridge University Press, 2013.

Sutherland, William J., Philip W. Atkinson, et al. ‘A Horizon Scan of Global Biological Conservation Issues for 2022’. *Trends in Ecology & Evolution*, vol. 37, no. 1, 2022, pp. 95–104.

Sutherland, William J., Erica Fleishman, et al. ‘Ten Years on: A Review of the First Global Conservation Horizon Scan’. *Trends in Ecology & Evolution*, vol. 34, no. 2, 2019, pp. 139–53.

Sutherland, William J., and Harry J. Woodroof. ‘The Need for Environmental Horizon Scanning’. *Trends in Ecology & Evolution*, vol. 24, no. 10, 2009, pp. 523–27.

Tang, Aaron, and Luke Kemp. ‘A Fate Worse Than Warming? Stratospheric Aerosol Injection and Global Catastrophic Risk’. *Frontiers in Climate*, vol. 3, Nov. 2021. *Frontiers*, https://doi.org/10.3389/fclim.2021.720312.

The Consilience Project. ‘Challenges to Making Sense of the 21st Century’. *The Consilience Project*, 30 Mar. 2021, https://consilienceproject.org/challenges-to-making-sense-of-the-21st-century/.

Troullinou, Pinelopi. *Exploring the Subjective Experience of Everyday Surveillance: The Case of Smartphone Devices as Means of Facilitating" Seductive" Surveillance*. 2017. Open University (United Kingdom), PhD Thesis, https://www.proquest.com/openview/f3077ea625b9d5e068f583f96319ce79/1?pq-origsite=gscholar&cbl=51922&diss=y.

Undheim, Trond Arne. *The Emergence of a Cascading X-Risks Paradigm Steeped in Transdisciplinarity*. The Stanford Existential Risks Initiative, 2023. *purl.stanford.edu*, https://doi.org/10.25740/pn116pv4512.

Vaccaro, Andrea. ‘Measures of State Capacity: So Similar, yet so Different’. *Quality & Quantity*, vol. 57, no. 3, June 2023, pp. 2281–302. *Springer Link*, https://doi.org/10.1007/s11135-022-01466-x.

Vecellio, Daniel J., et al. ‘Greatly Enhanced Risk to Humans as a Consequence of Empirically Determined Lower Moist Heat Stress Tolerance’. *Proceedings of the National Academy of Sciences*, vol. 120, no. 42, Oct. 2023, p. e2305427120. *pnas.org (Atypon)*, https://doi.org/10.1073/pnas.2305427120.

Vindman, Cindy, et al. *The Convergence of AI and Synthetic Biology: The Looming Deluge*. arXiv:2404.18973, arXiv, 29 Apr. 2024. *arXiv.org*, https://doi.org/10.48550/arXiv.2404.18973.

Workman, Mark, et al. ‘Decision Making in Contexts of Deep Uncertainty - An Alternative Approach for Long-Term Climate Policy’. *Environmental Science & Policy*, vol. 103, Jan. 2020, pp. 77–84. *ScienceDirect*, https://doi.org/10.1016/j.envsci.2019.10.002.

World Food Programme. ‘A Global Food Crisis | World Food Programme’. *A Global Food Crisis | World Food Programme*, https://www.wfp.org/global-hunger-crisis. Accessed 16 July 2024.

World Health Organization. ‘COVID-19 Cases | WHO COVID-19 Dashboard’. *Datadot*, https://data.who.int/dashboards/covid19/cases. Accessed 30 July 2024.

World Health Organization. *Emerging Trends and Technologies: A Horizon Scan for Global Public Health*. World Health Organization, 2022.

Xia, Lili, et al. ‘Global Food Insecurity and Famine from Reduced Crop, Marine Fishery and Livestock Production Due to Climate Disruption from Nuclear War Soot Injection’. *Nature Food*, vol. 3, no. 8, Aug. 2022, pp. 586–96. *www.nature.com*, https://doi.org/10.1038/s43016-022-00573-0.

Yang, Vicky Chuqiao, and Anders Sandberg. *Collective Intelligence as Infrastructure for Reducing Broad Global Catastrophic Risks*. The Stanford Existential Risks Initiative, 2023, https://doi.org/10.25740/pn116pv4512.

Acknowledgements

Special thanks to Alignment of Complex Systems Group, Wytham Abbey, Foresight Transitions for their logistical and funding support for this work. Thanks to Nafeesa Esmail and Bonnie Wintle for their advice in the opening stages, and Nathaniel Cooke for operational support in the initial phases and a suggestion regarding randomisation of issues in scoring.

Supplementary - A Horizon Scan of Global Catastrophic Risks

Definitions:

Civilisational Risk	*Civilisational risk broadly refers to a spectrum of risks, which represent the potential for a severe decline in global living standards, a permanent limitation to humanity's future potential, loss of 25% of the global population with disruption of critical systems, and even extinction.*[1] *It may prove helpful to think of this as 'Risk of Collapse + GCR + Extinction' cumulatively.*
Critical Transition	*Sharp shifts in systems driven by runaway change toward a contrasting alternative state once a threshold is exceeded (Scheffer et al., 2009).*
Extinction Risk	*The probability of human extinction within a given timeframe.*
Global Catastrophic Risk (GCR)	*The probability of a loss of 25% of the global population and the severe disruption of global critical systems (such as food) within a given timeframe (years or decades) (Kemp et al., 2022).*
Risk	*The potential for adverse consequences for human or ecological systems, recognising the diversity of values and objectives associated with such systems. In the context of climate change, risks can arise from potential impacts of climate change as well as human responses to climate change. Relevant adverse consequences include those on lives, livelihoods, health and well-being, economic, social and cultural assets and investments, infrastructure, services (including ecosystem services), ecosystems, and species (Pörtner et al., 2022b).*
Societal Collapse	*The severe, relatively rapid, and/or enduring loss of an established level of population density, energy capture, and coordination.*
Social Tipping Point	*Social tipping that cascades up scales could also play a vital role in positive change and could conceivably be deliberately nudged. Tipping a transition could start with changes in individual world views and consumer preferences, encouraged by the advent of plant-based substitutes for meat (e.g. the Impossible Foods burger), with social reinforcement of choices tipping abrupt change in social norms and policy (Lenton T., 2020).*
Tipping Points	*A level of change in system properties beyond which a system reorganises, often in a non-linear manner, and does not return to the initial state even if the drivers of the change are abated (Pörtner et al., 2022b). Often critical transitions or thresholds are used interchangeably (Munson et al., 2018).*

Table 1. Guiding definitions for the horizon scan.

[1] We are using it as an umbrella term for GCR, XR, Collapse, and protracted stagnation limiting future potential.

Issue	Participant Score			Participant Rank			Rank	
	I	**J**	**K**	**I**	**J**	**K**	**Median**	**Final**
A	124	43	218	3	2	2	2	2
B	948	519	800	1	1	1	1	1
C	323	9	145	2	3	3	3	3

Table 2. An example of how the scoring and ranking were used for this exercise.

The categorisation of many interdisciplinary and intersectional issues could be contentious, particularly when some issue categories such as Climate, Environment and Ecology contain significantly more issues (n = 12) than other categories such as Nuclear Weapons (n = 1) and Systemic Risks (n = 4). The overall result suggests that most topics experienced a drop in prediction score after the horizon scan exercise. Exceptions are issues classified in Nuclear Weapons, Food Security (n = 2), Epistemics (n = 2), and Space (n = 1). The uneven distribution of issues could likely reflect the domain expertises of invited participants and their ability to provide issues that track the criterias of specificity and tipping points it was assessed by.