Global
Challenges
Foundation

Global Catastrophic Risks 2018

GLOBAL CHALLENGES ANNUAL REPORT: GCF & THOUGHT LEADERS SHARING WHAT YOU NEED TO KNOW ON GLOBAL CATASTROPHIC RISKS 2018

The views expressed in this report are those of the authors. Their statements are not necessarily endorsed by the affiliated organisations or the Global Challenges Foundation.

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THE GLOBAL CHALLENGES FOUNDATION works to incite deeper understanding of the global risks that threaten humanity and catalyse ideas to tackle them. Rooted in a scientific analysis of risk, the Foundation brings together the brightest minds from academia, politics, business and civil society to forge transformative approaches to secure a better future for all.

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University of BRISTOL

Contents

Dear reader,

The 2018 Annual Report on global catastrophic risks presents updates to previously published information about global catastrophic risks and their governance, outlined and explained by leading academic experts.

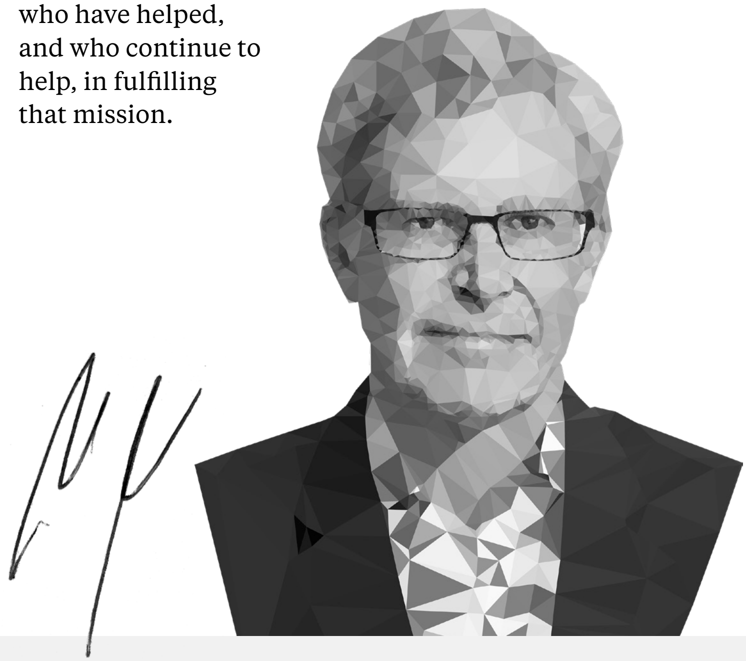
Understanding global catastrophic risks is more important than ever. It is also vital to realise that many of the risks are connected and often reinforcing each other. In that regard, the present report plays an essential role in the broader mission of the Global Challenges Foundation. Without an intimate knowledge of these threats, we cannot even begin to work on models that can help us manage, reduce and preferably eliminate the greatest threats to humanity more rapidly, effectively and equitably.

Since the last Annual Report, the Global Challenges Foundation organised the inaugural New Shape Forum, held in Stockholm on May 27-29 2018. More than 200 leading thinkers and experts convened to discuss fresh ideas for improving global governance to tackle the world's most pressing problems. During this event, we awarded a total of USD 1.8 million to three innovative submissions in the conclusion of the New Shape Prize, an open call seeking such creative models for better global governance.

In the coming months, we will continue to support the refinement and development of ideas to improve the ways we manage global risks. The Global Challenges Foundation has decided to fund a number of dedicated working groups who will concentrate on expanding the most promising ideas brought forward by the New Shape Prize. These groups will have the opportunity to present at the Paris Peace Forum in early November to an audience of world leaders and global shapers.

Still, this is just another checkpoint in an ongoing process of iterative elaboration and refinement. For now, we hope that the knowledge and insights shared here can stoke new productive ideas and even greater discussion about more effective forms of global cooperation.

For the Global Challenges Foundation, it remains an important task to develop our knowledge about the greatest global risks. We are grateful to all the scientists and experts who have helped, and who continue to help, in fulfilling that mission.

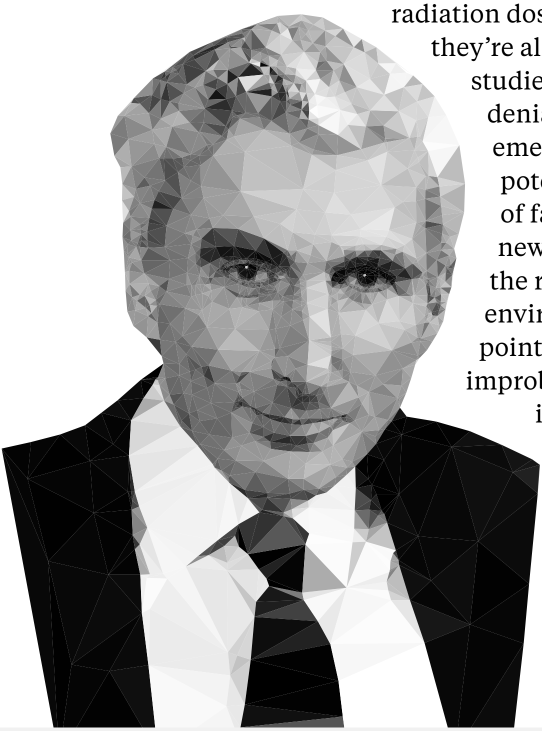


MATS ANDERSSON
Vice Chairman, Global Challenges Foundation

WHAT IS A GLOBAL CATASTROPHIC RISK?

Level of risk = probability x impact

We fret about familiar risks – air crashes, carcinogens in food, low radiation doses, etc – and they're all intensively studied. But we're in denial about some emergent threats – the potential downsides of fast-developing new technologies and the risk of crossing environmental 'tipping points'. These may seem improbable, but in our interconnected world, their consequences could cascade globally, causing such devastation that even one such incident would be too many. These potentially catastrophic threats surely deserve expert analysis. It's crucial to assess which can be dismissed firmly as science fiction, and which could conceivably become real; to consider how to enhance resilience against the more credible ones; and to guard against technological developments that could run out of control. This topic should be higher on the international agenda. It's a wise mantra that 'The unfamiliar is not the same as the improbable'. And that's why the topics addressed in these pages are so timely and deserve to be widely read.



MARTIN REES

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Why care now?

As a world leader, community leader, or global citizen,
there is a broad range of issues that you could be concerned about. Why should global catastrophic risks be the priority?

What do we have to lose?

Whatever you care most about, be it justice, knowledge, achievement, or family, it is likely to require this planet. Conserving this world is a prerequisite for the continued existence of everything we know and fight for.

Systemic risks

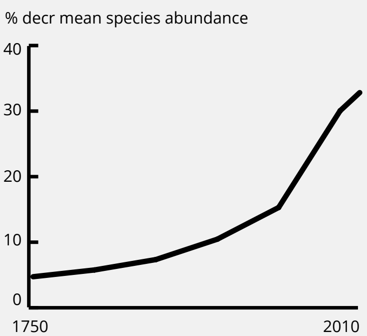
Many critical challenges today, such as climate change and political violence, are not contained within national borders, nor do they fit into the silos of separate government agencies or academic specialties. No matter who burns fossil fuels, the world's oceans continue to absorb carbon dioxide, and the resulting acidification affects fisheries and food security for millions.

Many studies have shown that poverty is a significant contributor to political violence[1], which in turn further impairs economic development. **Today's risks are interconnected. We cannot view them or manage them in isolation.** Leaders can ignore them because they fall outside the limited scope of their mandate, but silos will not offer protection from the consequences.

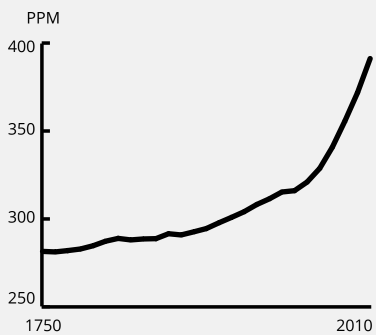
The limits of our cognitive ability

We're affected by cognitive bias. Our brain is not optimized to think about catastrophic risk. It either completely neglects or massively overweighs low probabilities[2], and it is wired to make sense of linear correlations[3]. However, most of our greatest challenges are non-linear: beyond a certain threshold, change is sudden, rapid, and sometimes exponential. This directly betrays our cognitive expectations. **Global catastrophic risk is not an intuitive matter, and as such, it requires intellectual focus.**

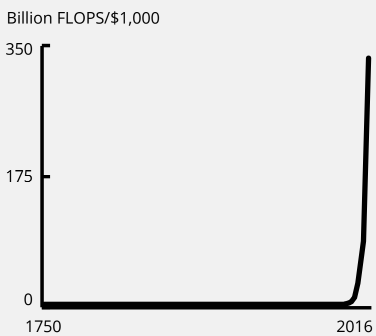
Striking exponential developments



Terrestrial biosphere degradation[4]



Carbon dioxide[4]



Advances in digital technology[5]

?

Institutional development

Scenario 1:

100%

of humanity is alive and well

Scenario 2:

1%

A catastrophe kills 99% of the world's existing population

Scenario 3:

0%

A catastrophe kills 100% of the world's existing population

Imagine the three scenarios above, where is there the most difference in terms of human loss? Is it between scenarios 1 and 2, or between scenarios 2 and 3? Instinctively, we might think that the death of 99% of humanity marks greater loss. But the difference between 1% surviving or nobody is far greater: in the case of complete extinction, no future generations will ever come to be, and all of humanity's potential will be lost[6].

The risks addressed in this report are not only catastrophic in terms of suffering and economic loss: at the extreme end of the scale, many of them could cause human extinction, and never give these future generations a chance to live. Putting it in purely numerical terms, there are currently 7.5 billion people alive. Although we know that our planet is not eternal, scientists have postulated that the world will remain habitable for a few hundred million years at least[7]. Over that period, hundreds of millions of generations could come to the world. But even **if humanity was to live for only 10,000 more years, maintaining its current size, this would add up to at least 2000 billion lives**. The potential of the far future is immeasurable and, unfortunately, systematically neglected.

Knowledge = opportunity

For the first time in human history, we have reached a level of scientific knowledge that allows us to develop an enlightened relationship to risks of catastrophic magnitude. **Not only can we foresee many of the challenges ahead, but we are in a position to identify what needs to be done in order to mitigate or even eliminate some of those risks.** Our enlightened status, however, also requires that we consider our own role in creating those risks, and collectively commit to reducing them.

Navigating suddenness

Emerging risks like synthetic biology or nanotechnology might seem far-removed, but a mere 100 years ago, weapons of mass destruction, climate change, and AI were not part of our lexicon either. From the time that climate change was recognised as both man-made and potentially catastrophic to the time when effective cooperation started, the risk increased dramatically, putting us all in jeopardy. Fostering better foresight and responsiveness in our institutions is essential to prepare for new risks on the horizon.

The next 50 years will determine the next 10,000 years

This report focuses on the greatest of our present risks, with potential for catastrophic damage. However, if we consider environmental risks alone, the last 50 years of human activity have pushed us away from the environmental stability of the past 12,000 years[8]. As global temperature continues to rise, the possibility that may trigger catastrophic disasters increases in tandem. The need for decisive leadership and citizen initiatives to shift businesses, politics and society onto a sustainable path has never been greater than today. The extent to which we protect our natural environment and transform harmful patterns of consumption in the next 50 years will shape our far future, over the next 10,000 years and beyond. **So why care now? Because so much is at stake, too little is done, and if we wait until later, caring may no longer matter.**

Taxonomy

This report aims to present an overview of the global catastrophic risks that the world currently faces, based on consideration of certain crucial facts and the latest scientific research. It proposes to complement the World Economic Forum's Global Risks Report[1], which offers an up-to-date picture of global risks as perceived by leading political and economic actors. These two approaches are highly complementary: perception is a strong driver of collective action and decision-making, while a more focused examination of the risks themselves will guide better long-term strategy and support the design of more efficient governance models.

When preparing this report, we aimed to develop a taxonomy that would reflect the best current understanding and be useful to decision-makers. We combined historical evidence and scientific data to decide which risks should be included in the report. For the sake of clarity, we identified ten key risks, which we then organised into three main categories: current risks from human action, natural catastrophes, and emerging risks. The reader should keep in mind, however, that many of those risks are closely interconnected, and their boundaries sometimes blur, as with climate change and ecological collapse, or as in the case of synthetic biology, which could be presented as a risk of its own, an additional risk factor in biological warfare, or a potential cause for engineered pandemics.

The first part of this report offers a description of the current risks, exploring what is at stake, what is known, and key factors affecting risk levels. The second part of this report considers current governance frameworks for mitigating the risks. Each section was prepared in collaboration with leading experts in the field.

CURRENT RISKS FROM HUMAN ACTION

Weapons of mass destruction – nuclear, chemical and biological warfare – catastrophic climate change and ecological collapse are all current risks that have arisen as a result of human activity. Although action on them is time sensitive, they are still within our control today.

NATURAL CATASTROPHES

Pandemics, asteroid impacts and super-volcanic eruptions are known to have caused massive destruction in the past. Though their occurrence is beyond human control to a large extent, our actions can significantly limit the scale of impact. This is especially true for pandemics, where the recent experience of Ebola and Zika outbreaks highlighted the challenges and opportunities of global cooperation.

EMERGING RISKS

Artificial intelligence, nanotechnology, geo-engineering or risks as yet unknown[2] might not seem like an immediate source of concern. However, we should remember that challenges widely recognized as the greatest today – climate change and nuclear weapons – were unknown only 100 years ago, and late response – as in the case of climate change – has increased the risk level considerably. Significant resources are devoted to further the potential of those technologies; In comparison, very little goes into mapping and managing the new dangers they bring. As we cannot expect the pace of technological development to be linear, and given our limited knowledge and resources, leading experts are pressing for action on those risks today[3].

Part 1

Understanding the risk

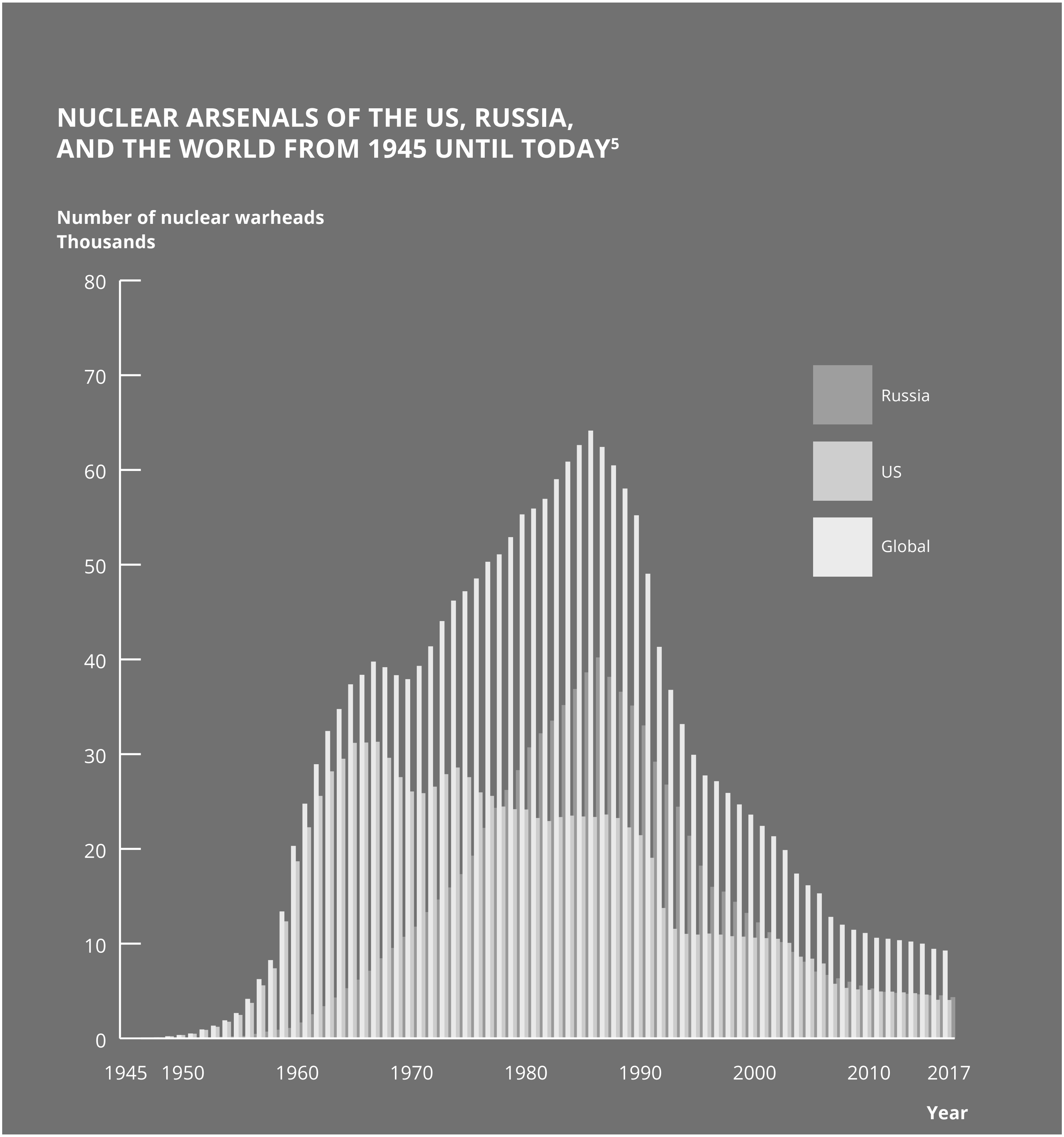
Weapons of Mass Destruction

Nuclear warfare

On August 6, 1945, a nuclear bomb exploded in Hiroshima, killing some 70,000 people within the day. In total, almost a half of the city perished from the effects of the bomb, half in the heat, radiation, fires and building collapses following the blast, and another half before the end of the year from injuries and radiation, bringing the total number of deaths to some 150,000[1]. Since then, the world has lived in the shadow of a war unlike any other in history. Although the tension between nuclear states has diminished since the end of the Cold War and disarmament efforts have reduced arsenals, the prospect of a nuclear war remains present, and might be closer today than it was a decade ago[2]. Its immediate effect would be the catastrophic destruction of lives and cities, and debilitation, illness and deaths from radiation, but another concern is the risk that the dust released from nuclear explosions could plunge the planet into a mini ice-age[3], with dramatic ecological consequences, severe agricultural collapse, and a large proportion of the world population dying in a famine[4].

Biological and chemical warfare

Toxic chemicals or infectious micro-organisms have been used as weapons to harm or kill humans for millennia, from the ancient practice of poisoning an enemy's wells and throwing plague-infected bodies over the walls of cities under siege, to the horrifying usage of germ warfare during the Second World War in Asia, or the use of nerve gases in the Iran-Iraq War. Biological and chemical attacks not only cause sickness and death but also create panic. Up to now, their destructive effect has been locally contained. However, new technological developments give cause for concern. In particular, developments in synthetic biology and genetic engineering make it possible to modify the characteristics of micro-organisms. New genetically engineered pathogens – released intentionally or inadvertently – might cause a pandemic of unprecedented proportions.


NUCLEAR ARSENALS OF THE US, RUSSIA, AND THE WORLD FROM 1945 UNTIL TODAY[5]
Number of nuclear warheads
Thousands
80
70
60
50
40
30
20
10
0
Russia
US
Global
1945
1950
1960
1970
1980
1990
2000
2010
2017
Year

Reviewed by
KENNETTE BENEDICT

Reviewed by
AMBASSADOR NOBUYASU ABE

Nuclear Warfare

HOW MUCH DO WE KNOW?

Depending on their yield, technical characteristics and mode of explosion, today's more powerful nuclear weapons will cause 80 to 95% fatalities within a radius of 1 to 4 km from their point of detonation, and very severe damage for up to six times as far[5]. The largest arsenals are currently held by the US and Russia, who control approximately 7,000 warheads each[6]. Seven other States are known to or widely believed to possess nuclear weapons: the UK, France, China, India, Pakistan, North Korea and Israel[7]. Various scenarios of intentional use are currently imaginable, but nuclear weapons could also be released by accident, and trigger an inadvertent nuclear war – as almost happened a number of times since 1945[8].

In addition to their destructive effect at the point of impact, nuclear explosions may cause what is known as a 'nuclear winter'[9], where clouds of dust and sulphates released by burning materials obscure the sun and cool the planet for months or years. According to one model, an all-out exchange of 4,000 nuclear weapons, in addition to the enormous loss of lives and cities, would release 150 teragrams of smoke, leading to an 8 degree drop in global temperature for a period of 4 to 5 years[10], during which time growing food would be extremely difficult. This would likely initiate a period of chaos and violence, during which most of the surviving world population would die from hunger.

WHAT ARE KEY FACTORS AFFECTING RISK LEVELS?

- **Continued efforts** towards arsenal reduction will reduce the overall level of nuclear risk, while attention to geopolitical tensions and continued efforts towards global conflict management, particularly among nuclear states, will reduce the underlying risk of an intentional nuclear war[11]. In addition, controlling and limiting horizontal proliferation[12] will limit the number of potential nuclear conflict scenarios, and is highly likely to reduce the overall risk level.
- **The risk of accidental use** depends largely on the systems in place to launch missiles. Hundreds of nuclear weapons are currently in a state of high readiness, and could be released within minutes of an order[13]. Building in longer decision making time and broader consultation would reduce the risk of unauthorized launches or accidental launches based on misperception or false alarms.
- **Increased awareness** and understanding of the grave effects that nuclear weapons have on human life, economic infrastructure, governance, social order and the global climate, would motivate efforts to avoid such catastrophic harm to our societies[14].

NUCLEAR SECURITY

The production of a nuclear weapon requires rare materials, whose production in turn requires sophisticated machinery[15]. This limits the risk of proliferation. However, stocks of those materials exist in countries that possess nuclear weapons, and their storage conditions raise security concerns. In addition, nuclear technology used for civilian purposes – energy production, industrial and medical use principally – yields materials that could be used for destruction, in the form of a so called 'dirty bomb' spreading radioactive materials over a large radius[16]. If they were to appropriate nuclear materials, sub-national groups could target a major urban centre and, depending on the type of bomb used, cause hundreds or thousands of deaths, and contaminate an area for decades[17]. Although it is highly improbably that this scenario would escalate to a global nuclear war, it could have a major disruptive effect on social and economic systems[18].

PROBABILITY OVER TIME

When we hear that the probability of a global nuclear war is estimated to be no more than 1%, 0.1% or 0.01% every year, this may sound reassuringly low – but how does this compound over time? Let's imagine that you flip a coin exactly once every year. What is the probability that no single coin flip will fall on heads in a certain amount of years? Over the course of one year the probability is 50%. Over two years, it goes down to 25%, 12.5% over three years, 6.25% over four years, and so on along an exponential curve. Using the same logic, if there was a 99.9% probability that we won't have a global nuclear war in a given year, this number goes down along a similar exponential curve to just above 99% over the course of a decade, and about 90.5% over a century – or a 9.5% probability that a global nuclear war would occur.

However, two elements challenge this purely logical model. First, the reasoning presupposes that probability remains stable over time, which is empirically unlikely. In the case of nuclear war, for instance, the absence of any incident might increase the sense of safety, leading to relaxed security measures, and a greater probability that an incident would occur. Second, risk estimates are often contentious to start with, and our understanding of interconnected causal chains decreases over time. This is why probabilities are typically given as a bracket rather than a single number – acknowledging that all predictions about the future include margins of uncertainty but that we can, nonetheless, produce educated estimates.

Today's more powerful nuclear weapons will cause up to

95%

fatalities within a radius of 1 to 4 km from their point of detonation, and very severe damage for up to six times as far.

CLOSE CALLS

The most dangerous nuclear war scenarios may be those resulting from an accident or misperception. Close calls have occurred a number of times since 1945.

During the Cuban missile crisis, in **October 1962,** the United States targeted a Soviet submarine that carried nuclear weapons. Two of the three Soviet officers wanted to launch nuclear weapons in response. The procedures required agreement between all three. Vasili Arkhipov, the third officer, refused, potentially averting nuclear war.

In **September 1983,** a Soviet satellite detected five missiles directed at the Soviet Union. The officer on duty, Stanislav Petrov, had minutes to decide whether this was a false alarm. Procedure would have required him to alert his superiors but, on gut instinct, he reported the incident as a false alarm. Investigations later revealed that reflections of the sun on the top of clouds had been mistaken for nuclear rockets.

On **January 25, 1995,** Russian radar detected a scientific weather rocket over the northern coast of Norway. Operators suspected it was a nuclear missile. President Yeltsin reportedly faced the decision to launch nuclear weapons in retaliation. He decided not to, guessing – correctly – that the rocket was not an actual attack.

Similar close calls in the future have the potential to trigger a global nuclear war[19].

Reviewed by
ANGELA KANE

Biological and chemical warfare

HOW MUCH DO WE KNOW?

Unlike nuclear weapons, which require rare materials and complex engineering, biological and chemical weapons can be developed at a comparatively low cost[20], placing them within the reach of most or all states as well as organized non-state actors. Chemical and biological weapons carry various levels of risk. Toxic chemicals could be aerosolized or placed into water supplies, eventually contaminating an entire region. Biological weapons possess greater catastrophic potential, as released pathogens might spread worldwide, and cause a pandemic.

Recent developments in synthetic biology and genetic engineering are of particular concern[21]. The normal evolution of most highly lethal pathogens ensures that they will fail to spread far before killing their host. Technology, however, has the potential to break this correlation, and create both highly lethal and highly infectious agents[22]. Such pathogens could be released accidentally from a lab, or intentionally released in large population centres[23]. Current trends towards more open knowledge sharing can both contribute to and mitigate such risks.

WHAT ARE KEY FACTORS AFFECTING RISK LEVELS?

- **Global frameworks** controlling research on chemical or biological weapons including revised strategic trade controls on potentially sensitive dual-purpose goods, technology and materials, biological and chemical safety and security measures, as well as an ongoing commitment and capacity to enforce disarmament and arms control conventions[24].
- **The number of laboratories** researching potential pandemic pathogens for military or civilian purposes, and the public availability of dangerous information circulating for scientific purposes, increase the level of risk[25].
- **Further developments** in synthetic biology and genetic engineering lowering skill levels and costs to modify existing pathogens or to develop new pathogens which, in turn, may significantly increase biological risks to society[26].

CHEMICAL WEAPONS: AN UNRAVELLING CONSENSUS?

Deadly agents like sulphur mustard were used during and between the World Wars, but the horrific results of such attacks eventually led to a global consensus to ban toxic chemical weapons, the most widely-used and easily proliferated weapon of mass destruction[27].

This consensus, however, represented by the near-universal 1993 Chemical Weapons Convention (CWC) is under strain. The Syrian Civil War has resulted in well-documented and indiscriminate uses of various deadly toxic chemicals against the civilian population, most recently in Khan Sheikhoun on 4 April[28]. **The Khan Sheikhoun attack resulted in at least 85 victims – including some 20 children – dying from the deadly nerve agent Sarin (or 'sarin-like' compound).** Though the risk may always exist from easily available dual-use chemicals, and from terrorists like the Aum Shinrikyo, which perpetrated the Tokyo attack in 1995, there is a global risk that the hard-won consensus on banning state-use of toxic chemicals will be further weakened[29]. This could lead to the devastating return of more advanced toxic chemical weapons of mass destruction in any potential large-scale conflict in the future, as well as long-term changes in how states understand the development, evaluation and use of 'non-standard chemical substances' (substances other than deadly substances like sarin) for domestic riot control purposes, counter-terrorism operations, international peacekeeping operations, and as a mechanism to maintain a standby offensive chemical weapons capability.

RECENT USAGE

Though their production and use is banned by International conventions, biological and chemical weapons have been used at least on four occasions in the last forty years, three times in war, and once in an act of terrorism:

Rhodesia, late 1970s: cholera, anthrax, epidemic typhus and typhoid fever pathogens were released in water supplies used by guerillas.

Iraq-Iran, 1980-1988: mustard gas used in trench warfare killed 20,000 and affected 100,000. In March 1988, poison gas killed between 3,200 to 5,000 people in Halabja and injured 7,000 to 10,000 more. Thousands have since died prematurely of the after-effects. Others continue to receive medical treatment and/or remain under periodic medical observation and care.

Japan, March 1995: Sarin gas released on trains in Tokyo by the Aum Shinrikyo cult killed 12 people, and severely injured 50.

Syria, 2012 – 2017: Sarin and chlorine gas attacks have been recurring and are still ongoing. The most lethal attack killed 837 people in August 2013, another killed up to 100 on April 2017[30].

Catastrophic climate change

WHAT IS AT STAKE?

Discussions of climate change typically focus on low- to mid-range scenarios, with temperature increase of 1°C to 3°C[1]. These would have severe consequences, with potentially devastating effects on the environment and human societies. However, there is also a non-negligible and less often considered 'tail-end' risk that temperatures might rise even further, causing unprecedented loss of landmass and ecosystems[2]. Global climate models indicate that even in a <2°C scenario, the most intense tropical cyclones become more frequent and more intense[3]. In mid-range scenarios, entire ecosystems would collapse, much agricultural land would be lost, as would most reliable freshwater sources, leading to large-scale suffering and instability[4]. Major coastal cities – New York, Shanghai, Mumbai – would find themselves largely under water[5], and the populations of low-lying coastal regions – currently more than a billion people[6] – may need to be relocated. In high-end scenarios, the scale of destruction is beyond our capacity to model, with a high likelihood of human civilization coming to an end.

HOW MUCH DO WE KNOW?

The Earth's climate is impacted by the concentration of certain gases in the atmosphere, known as greenhouse gases, the most important being carbon dioxide and methane. As a result of human activity since the Industrial Revolution, the atmospheric concentrations of greenhouse gases – generally expressed as the number of greenhouse gas molecules per million or PPM – have risen consistently, reaching 400 ppm in 2015 and 403.3 ppm in 2016 from 280ppm at the dawn of the Industrial Revolution. When similar levels were last observed 3-5 million years ago, temperatures were 2-3°C warmer and sea levels 10-20 meters higher[7]. Scientists had demonstrated an approximately linear relationship between the total amount of greenhouse gases emitted and the resulting temperature increase[8]. There is now also a scientific consensus that climate change is a non-linear phenomenon where tipping points play a determining role[9]. When warming rises above a certain level, self-reinforcing feedback loops set in, and the concentration of greenhouse gases increases rapidly[10].

Although precise thresholds and exact scenarios remain uncertain, we know that the level of risk increases with the rise in temperature[11]. The emissions pledge pathway negotiated at the Paris conference has a probability of over 90% to exceed 2°C, and only a 'likely' (>66%) chance of remaining below 3°C this century[12]. In other words, even if current commitments were kept, there would remain a one-third probability of climate change in excess of 3°C – and we are presently not on track to meet the pledges.

After years of effort and considerable resources devoted to airplane safety, we have reached a point where 27 planes crash on average every year. If dying in a flight accident was as likely as a 3°C global temperature increase, then the number of people dying in airplanes every year would be 15,000,000[13].

Reviewed by
LEENA SRIVASTAVA

AT 3°C

If climate change was to reach 3°C, most of Bangladesh and Florida would drown, while major coastal cities – Shanghai, Lagos, Mumbai – would be swamped, likely creating large flows of climate refugees. Most regions in the world would see a significant drop in food production and increasing numbers of extreme weather events, whether heat waves, floods or storms[14]. This likely scenario for a 3°C rise does not take into account the considerable risk that self-reinforcing feedback loops set in when a certain threshold is reached, leading to an ever-increasing rise in temperature. Potential thresholds include the melting of the arctic permafrost releasing methane into the atmosphere, forest dieback releasing the carbon currently stored in the Amazon and boreal forests, or the melting of polar ice caps that would no longer reflect away light and heat from the sun.

CITIES FACING THE HIGHEST RISK FROM COASTAL FLOODING

Coastal cities are at particular risk from climate change, in developed and developing countries alike. This is of particular relevance as 1 billion people are currently estimated to live in coastal areas, lower than 20m above sea level, many of them in Asia[15].

According to one study, taking the absolute estimated value of potential losses as a basis, the following cities face the highest risk from coastal flooding by 2050:

1. Guangzhou, China
2. Mumbai, India
3. Kolkata, India
4. Guayaquil, Ecuador
5. Shenzhen, China
6. Miami, USA
7. Tianjin, China
8. New York, USA
9. Ho Chi Minh City, Vietnam
10. New Orleans, USA

The risk of climate change for coastal cities can be measured in multiple ways. If we were to consider the increase in the level of risk, which may catch a city unprepared and cause sudden catastrophe, then, according to the same study, Alexandria, Barranquilla, Naples, Sapporo, and Santo Domingo face the greatest danger[16].

WHY ICE MATTERS?

The Arctic region, mostly consisting of oceans, is covered with an ice sheet spanning about 14.4 million km^2 , or approximately half the size of Africa[17]. Ice is reflective, and therefore absorbs less of the sun's heat and energy. When it melts under the effect of climate change, to be replaced with open ocean, the amount of solar radiation reflected back to space is reduced, and the result is further warming of the planet[18].

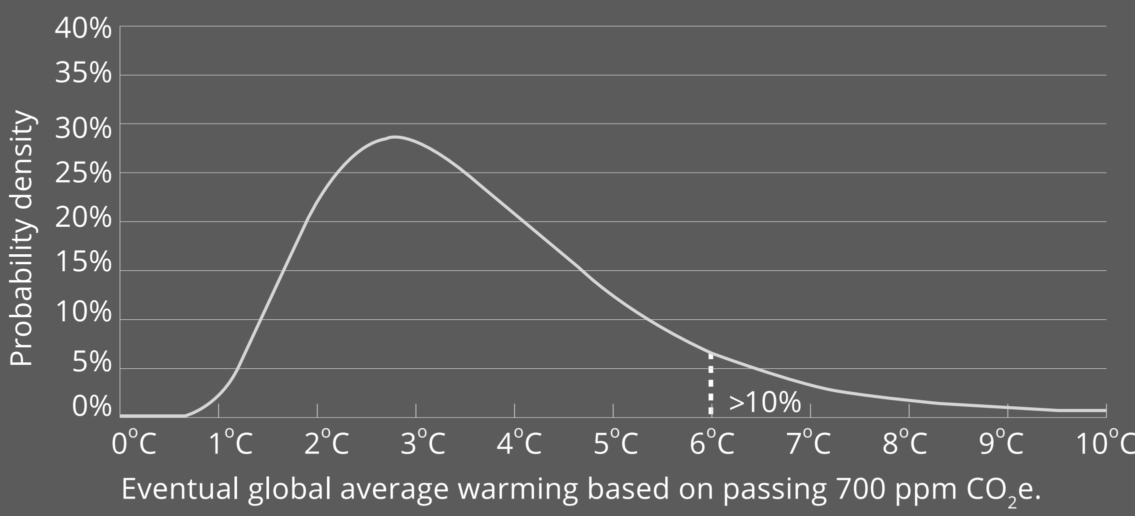
Large quantities of water are also currently stored in frozen form on land – most of it over Greenland, Antarctica, and in mountain ranges as glaciers. It is predicted that approximately 1 meter of sea level rise from the melting of land ice is currently unavoidable, but things could get worse[19]. If the entire Greenland ice sheet was to melt, it could potentially raise the world's oceans by more than 6 meters. If all the ice currently standing on land and at the poles melted, at current estimates, sea levels would rise by more than 65 meters[20], flooding much of the planet's inhabited land on all continents.

WHAT ARE KEY FACTORS AFFECTING RISK LEVELS?

Climate change is a complex phenomenon affected by many factors. We may classify them into four categories to better discern the various areas where action is possible:

- **The risk is directly related** to the release of greenhouse gases in the atmosphere through human activity. Carbon dioxide mainly results from the burning of fossil fuels for energy and transport. In turn, this is a factor of population growth and unsustainable production and consumption models[21]. As to methane emissions, they largely relate to large-scale animal farming, driven by demand for meat, wool and dairy.
- **Some ecosystems** store large amounts of carbon, particularly forests and coastal marine ecosystems[22], and their destruction could result in the large-scale release of greenhouse gases in the atmosphere.
- **The third factor** is our capacity for global coordination to reduce emissions. This may be positively impacted by a better understanding of tail-end climate risk and climate tipping points, increasing the sense of urgency and prompting faster action[23].
- **Finally,** the risk of catastrophic climate change is increased by insufficient knowledge and understanding of impacts and vulnerability, in turn affecting our ability to build resilience. The complex and interrelated nature of global catastrophic risk suggests an integrated research agenda to address related challenges and dilemmas – such as the use of solar geoengineering to reduce the risk of catastrophic climate change, which might harm in other ways – and keep human development safe[24].

CLIMATE CHANGE LONG TAIL[25]



DISPLACEMENT DUE TO CLIMATE CHANGE

An important effect of climate change is an increase in the frequency and magnitude of extreme weather events - floods and storms principally - that affect the built environment, access to drinking water and other resources to support daily life, as well as social structures, and often result in the displacement of populations. Although precise attributions of causality can be complex, there is significant quantitative and qualitative data on past displacement associated with natural hazards and disasters. According to the Internal Displacement Monitoring Centre's 2015 Global Estimates report, **since 2008, an average of 26.4 million people per year have been displaced from their homes by disasters brought on by natural hazards, 85% of those weather-related.** This is equivalent to one person displaced every second.[26]

CIVILIZATIONS LOST TO CLIMATE CHANGE

History records at least three instances of past civilizations collapsing under the local effects of climate change.

Norse Viking settlers arrived and thrived in Greenland during the medieval warm period (800-1200 AD). When a period of cooling known as the Little Ice Age began in the early 14th century, it became increasingly difficult to farm. By the middle of the 16th century, the changing climate had contributed to the Vikings deserting their settlements and moving on to warmer lands[27].

The Khmer Empire flourished from 802 to 1431. Its capital of Angkor Wat was one of the most ancient hydraulic cities, with a sophisticated system for irrigation to ensure optimal water reserves for the population's growing needs. In the 14th and 15th centuries, decades of severe drought struck, interspersed with violent monsoon floods, bringing about political and social unrest which eventually led to the empire's collapse[28].

From 3300 to 1700 BC, the Indus Valley Civilization developed sophisticated infrastructure and urban planning, and the population is estimated to have reached over 5 million. A 200-year drought that began around 2000 BC made agriculture unsustainable, and cities were gradually abandoned[29].

In all three instances, climate change was local, its cause was independent from human action, and the civilizations affected could not anticipate the change in their natural environment. The global nature of the climate change risk we face today bodes ill for humanity. If our civilization collapses on this planet, there is currently no alternative location where humanity may thrive. However, scientific and technological developments have made us more aware both of the risk we face, and of our influence on it. As a result, for the first time in history, we are in a position to reduce and possibly avoid the risk of civilization collapse due to climate change.

Ecological collapse

WHAT IS AT STAKE?

Ecosystems are the foundation for human life. They perform a range of functions, generally referred to as environmental services, without which human societies and economies could not operate at their current level[1]. We depend on the services they provide for air, water, food, shelter and energy. Ecosystems can tolerate a measure of impact from human use and recover relatively quickly with minimal negative effects – an attribute generally known as resilience – but beyond a certain threshold, or tipping point, sudden and radical disruption occurs. Under such conditions, soil quality, freshwater supplies and biodiversity diminish drastically, while agricultural capacity plummets and daily human living conditions deteriorate significantly[2].

Local ecological collapse may have caused the end of a civilization on Easter Island[3]. More recently, ecological collapse in and around the Aral Sea has had dramatic social and economic consequences for the region[4], although timely intervention has led to some marked recovery[5]. In today's highly connected world, local disruptions may sometimes also lead to unintended ecological effects on other far flung areas. This might escalate into the rapid collapse of most ecosystems across the Earth[6], with no time for effective recovery, drastically compromising the planet's capacity to sustainably support a large and growing human population.

HOW MUCH DO WE KNOW?

Ecosystems are complex entities, which consist of a community of living organisms in their non-living environment, linked together through flows of energy and nutrients. The behaviour of an ecosystem is relatively stable over time, but when the balance between some of its elements is altered beyond a certain threshold, it can experience a non-linear, possibly catastrophic transformation[7].

Human-induced factors that affect ecosystem vitality may be classified in the following manner:

- **changes in the balance of local biodiversity** caused by human intervention, in particular as a result of introducing new species or overexploitation[8]
- **alteration of the chemical balance** in the environment due to pollution[9]
- **modifications in the local temperatures** and water cycle because of climate change[10]
- **habitat loss,** whether through destruction or ecosystem fragmentation[11].

Scholars describe the current historical moment as the start of a new geological era, called the Anthropocene[12], where humans as the predominant agent of change at the planetary level change the nature of nature itself. Since the mid 1950s, many elements that ensure the habitability of the planet, whether greenhouse gas concentration, forested areas or the health of marine ecosystems, have been degrading at an accelerating pace[13]. In 2009, an international group of experts identified nine interconnected planetary boundaries that underpin the stability of the global ecosystem, allowing human civilization to thrive[14]. Research indicates that we have exceeded safe limits for four of those, and are now operating in a high-risk zone for biosphere integrity

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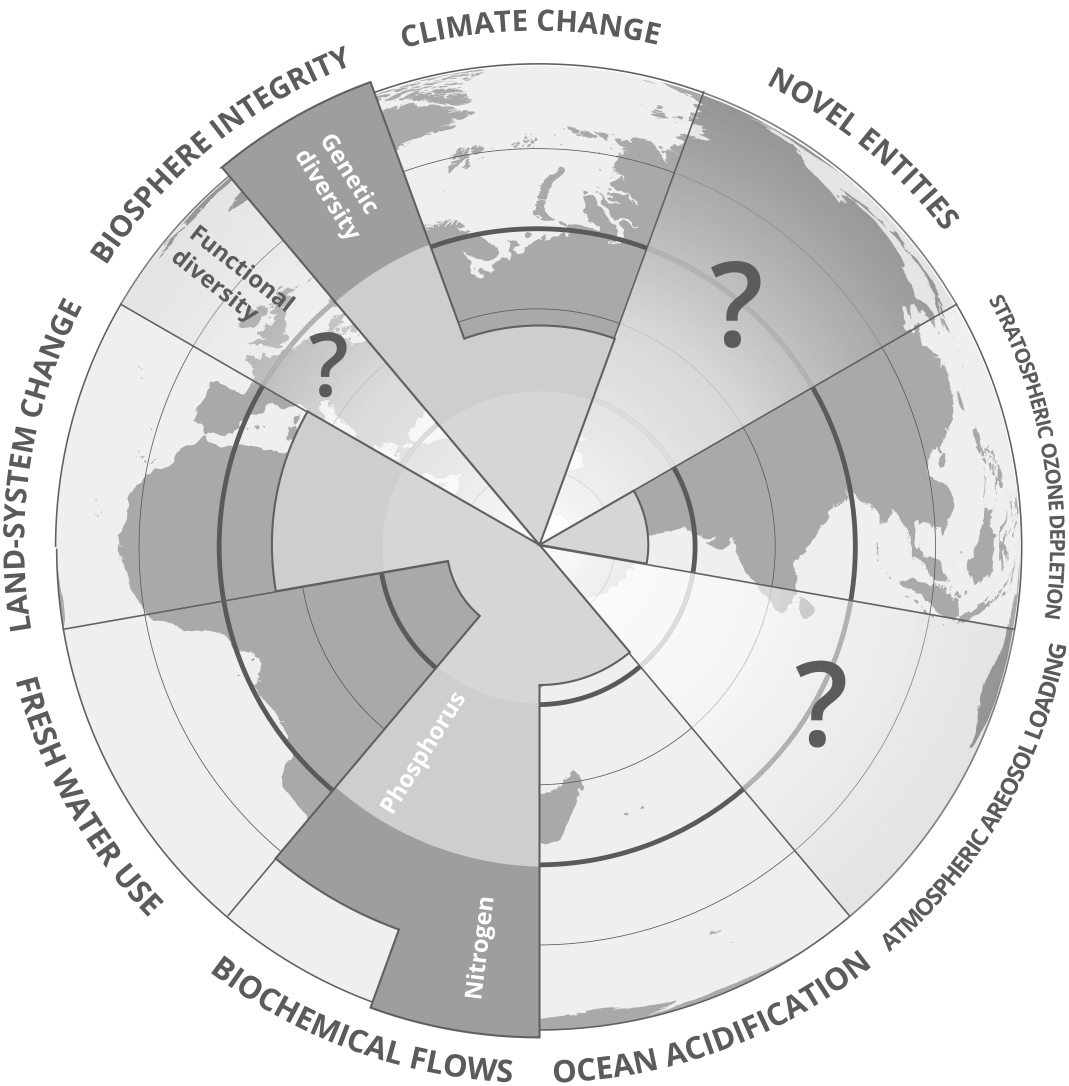
PLANETARY BOUNDARIES



In 2009, an international group of experts proposed a framework of nine planetary boundaries that underpin the stability of the global ecosystem, allowing human civilization to thrive. Each of the nine identified boundaries is characterized by thresholds or tipping points. Exceeding those carries a high risk of sudden and irreversible environmental change, which could make the planet less hospitable to human life. The latest research indicates that, as a result of human activity, we have now exceeded the safe limits for four of the nine identified planetary boundaries[15].

and biogeochemical flows[16]. Unless we rapidly change trends and adopt a new sustainable paradigm, we are very likely to exceed all nine boundaries, and leave the safe operating ecological space where humanity has thrived.

WHAT ARE KEY FACTORS AFFECTING RISK LEVELS?

- **The development** and adoption of new technologies or production models that are less resource-intensive and/or less polluting could reduce the risk of ecological collapse, as would a shift towards more sustainable lifestyles, more specifically changing consumption patterns, possibly accompanied by behaviour change[17].
- **It is estimated** that environmental services, should their contribution to human well-being be calculated, would be worth more than twice as much as the entire global GDP[18]. Integrating the valuation of ecosystems into economic decision making and employing robust environmental accounting systems across businesses and national economies would contribute to reducing the risk[19].
- **Global governance mechanisms** to preserve ecosystems and reduce pollution, in particular more integrated approaches between the governance of ecosystems and trade, are of particular importance, as many ecosystems do not overlap with national boundaries, and trade is an important driver of ecosystem collapse[20].

LAKE CHAD – AN EXAMPLE OF ECOLOGICAL COLLAPSE

The changes in Lake Chad have been called an ecological disaster that have not only destroyed livelihoods but also led to the loss of invaluable biodiversity. Lake Chad traverses Chad, Nigeria, Niger and Cameroon. The lake was considered as the sixth largest lake in the world in 1960s but over the last 60 years, the lake's size has decreased by 90 per cent as a result of over use of the water, extended drought and the impacts of climate change. The surface area of the lake has plummeted from 26,000 square kilometers in 1963 to less than 1,500 square kilometers today, affecting the livelihoods of over 40 million people that depend on it[21]. The fluctuation of the lake is attributed to the complex interaction of several factors, including the shallowness of the lake, changing human uses of the lake water such as increased water use for irrigation and the effects of climate change[22]. A scientific assessment on the situation of the lake ranked freshwater shortage as severe and as a primary concern affecting other changes, including habitat modification and declining fish production[23]. The diminishing water resources and the decline in the lake's ecosystem leads to severe health and economic impacts for the populations around Lake Chad, and has affected fishing communities and pastoralists, and also generated resource-based conflicts[24].

From 1970 to 2012 the Living Planet Index shows a

58%

overall decline in vertebrate population abundance.[25]

Pandemics

WHAT IS AT STAKE?

In the 5th and 14th century, Plague epidemics spread internationally and killed approximately 15% of the global population over the course of a few decades[1]. Systematic vaccination campaigns have allowed us to eradicate two diseases that had affected humanity for centuries, Smallpox in humans and Rinderpest in animals, and two more diseases – Guinea Worm and Polio – are close to being eradicated. Progress in medical treatment and public health systems has significantly reduced the prevalence and impact of others, such as Malaria, Typhus and Cholera. However, there remains a serious risk that the emergence of a new infectious disease in humans could cause a major outbreak, with particularly high mortality and rapid spread in our densely populated, urbanized and highly interconnected world.

HOW MUCH DO WE KNOW?

Catastrophic pandemics – diseases with high lethality that spread globally – are extremely disruptive, but very rare. Outbreaks of lethal diseases that remain locally contained or pandemics with less acute effects on human health are however more common, and can have significant disruptive effects.

Outbreaks occur when a micro-organism – virus, bacteria, parasite, etc. – is able to spread across the population. At times and under certain conditions, such as failure of water or sanitation systems, an outbreak is caused by a micro-organism known to be circulating at low levels in human populations. At others, an outbreak is caused by a micro-organism that has crossed the animal/human species barrier to infect humans, and spreads to new and more densely populated areas. If mutation occurs, virulence can increase or decrease. Mutation can also cause a micro-organism to transmit more easily from human to human.

RISK FACTORS[2]

Three main factors determine the potential danger of an outbreak:

1. **Virulence:** the ability of a micro-organism to damage human tissues and cause illness and death.

2. **Infection risk:** the probability that a micro-organism will spread in a population. One key factor is the means of transmission – whether by blood, bodily fluids, direct contact with a lesion such as a skin ulcer, or by aerosol in the air.

3. **Incubation period:** the time between infection and appearance of the first symptom(s). A longer incubation period could result in a micro-organism spreading unwittingly, as in the case of HIV. Conversely, a shorter incubation period, if the infection is highly lethal, is less likely to be transmitted unwittingly, and can cause considerable disruption of social, economic and medical systems in a very short period of time. The disruption caused by a highly lethal infection with a longer incubation period, such as HIV, is of longer term consequence.

Ebola is a highly lethal infection with a short incubation period but a relatively low infection rate, which explains why most Ebola outbreaks to date have been localized[3]. New developments in synthetic biology, however, raise concern among certain scientists that an engineered micro-organism both highly virulent and with a high infection rate could be released in the population – whether by malice or accident – and cause an unprecedented outbreak, possibly leading to the international spread of a highly lethal infectious disease.

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WHAT ARE KEY FACTORS AFFECTING RISK LEVELS?

- **New micro-organisms** affecting humans are more likely to arise when environments with high levels of biodiversity are disrupted, so that humans or domesticated animals come into close contact with other animal species that serve as reservoirs for micro-organisms not yet present in human populations[4]. Experts now consider this is likely to be the way that the HIV-AIDS pandemic started[5].
- **Infections are easier** to contain when they occur among small populations with limited external contacts. Conversely, dense urbanization and global interconnection strongly increases the risk of an infectious disease spreading internationally[6].
- **Access to healthcare** and the broad adoption of hygiene practices can have a significant effect in reducing the impact of a pandemic. The capacity to monitor a disease and deploy very rapid containment early in the process also has a large impact on the final number of deaths[7].

RISK SCENARIO

In February 2003, an elderly woman infected by the SARS virus travelled from Hong Kong to Toronto. SARS is a highly infectious and often fatal pulmonary disease that emerged in the Pearl River Delta, in China. The infected woman died soon afterwards in Toronto, after inadvertently infecting over forty people, resulting in a localized outbreak. One of those persons infected in Canada went on a plane to the Philippines, where another outbreak occurred. Meanwhile, from Hong Kong, the virus had also spread to Singapore, where it likewise caused an outbreak. The outbreaks that occurred around the world were eventually contained, after infecting over 8,000 people, of whom 774 died, through concerted public health action coordinated by the WHO. Severe social and economic disruption occurred, and a similar scenario with only minor variations – a few more international contacts, a slightly longer incubation period for the virus, or a few more days of delay in deploying strict containment measures, could have a similar or even greater outcome.

ANTIBIOTICS AND BACTERIA

Antibiotics have saved millions of lives and dramatically increased lifespans since they were introduced in the 1940s[8], allowing us to contain most bacterial infections and diseases. However, more recently, as a result of random mutations, improper use of antibiotics among humans and animals, and the build-up effects of evolution, some strains of bacteria have become resistant to traditional antibiotics. These 'superbugs' require alternative medications with more damaging side effects or, in the worst cases, can no longer be treated effectively. Antibiotic-resistant bacteria currently kill an estimated 700,000 people each year worldwide. That number is predicted to reach 10 million by 2050 if efforts are not made to curtail resistance or develop new antibiotics[9].

THE 5 DEADLIEST PANDEMICS IN HISTORY[10]

1. **165-180: the Antonine Plague** outbreak lasted for 15 years, killing an estimated 5 million people.
2. **541-542: the Plague of Justinian** took 25 million lives, or about 13% of the global population at the time.
3. **1347-1351: The Black Death** caused at least 75 million deaths from a global population of 450 million – with some estimates putting the figure as high as 200 million deaths.
4. **1918-1919: The Spanish Influenza** is estimated to have killed more than 50 million out of a global population of 1.6 billion.
5. **1970s-present: HIV/AIDS,** so far, has killed more than 25 million people.

Asteroid impact

WHAT IS AT STAKE?

Around 65 million years ago, an asteroid of about 10km in diameter struck Chicxulub in Mexico. This impact probably caused one of the three largest mass extinctions in history, abruptly ending the age of the dinosaurs[1]. Large asteroids still exist in orbits near the Earth's and the impact of an asteroid bigger than 1 km in size would eject enough particles into the atmosphere to dim the sun for a number of months[2]. The resulting cooling of the climate would undermine ecosystems and global agriculture for at least an entire growing season, and could cause a famine leading to the death of hundreds of millions[3].

HOW MUCH DO WE KNOW?

Asteroids are small rocks leftover from the formation of our solar system about 4.6 billion years ago. Too small to be called planets, they revolve around the sun, typically along elliptical orbits. The orbits of Earth and the asteroids can occasionally intersect and result in collisions.

The likelihood of asteroid-related risk is better understood than that of many other global catastrophic risks because the underlying dynamics have been well understood for a very long time. Many asteroids have hit Earth in the past, and more will continue to do so. While smaller objects would have only local effects, larger ones could cause a global cooling resulting in large-scale disaster[4]. On the basis of historical evidence, an asteroid impact large enough to cause a global catastrophe is estimated likely to occur every 120,000 years[5].

In 2011, NASA held a press conference announcing that over 90% of objects larger than 1 km in diameter had now been discovered, and none of those has been estimated likely to enter in collision with the Earth[6]. Currently there are no known objects of any size for which we have well-computed orbits that are predicted to have significant probability of hitting Earth. However, after more than twenty years of survey, the current data for smaller objects of 140 meters up to 1 kilometer in size is only about 30% complete for the estimated total population. Further monitoring is required to properly establish risk levels. Although unlikely to directly cause a global catastrophe by cooling the climate, those smaller objects could have significant local impact, and indirectly disrupt social and economic systems.

WHAT ARE KEY FACTORS AFFECTING RISK LEVELS?

- **It is technologically possible** to identify whether an asteroid is on a collision course with Earth long enough in advance, giving humanity time to react. However, many asteroids have not yet been spotted, and shorter reaction times would carry higher risk. Enhanced effort to detect and monitor asteroids would therefore decrease the risk[7].
- **New technologies** that could either deflect the trajectory of an asteroid or reduce its impact would considerably reduce the overall risk level[8].
- **Systematic monitoring** has considerably reduced the estimated risk of impacts from larger objects >1km that would significantly affect the climate. However, to address the remaining risk, resilience building, particularly the potential to rely on food sources less dependent on sunlight – mushrooms, insects, or bacteria – could significantly reduce the death rate among humans[9].

Reviewed by

TIM SPAHR

THE 5 LARGEST ASTEROID IMPACTS ON EARTH

1 **Vredefort Crater, South Africa** – Estimated impact date: 2 billion years ago. World's largest known impact structure, with an approximate diameter of 160km.

2 **Chicxulub Crater, Mexico** – Estimated impact date: 65 million years ago. Many researchers believe that this was the asteroid that caused or contributed to the extinction of the dinosaurs, with an approximate impact diameter of 150km.

3 **Sudbury Basin, Canada** – Estimated impact date: 1.8 billion years ago. Approximate diameter of 130km.

4 **Popigai Crater, Russia** – Estimated impact date: 35.7 million years ago. Approximate diameter of 90km.

5 **Acraman Crater, Australia** – Estimated impact date: 590 million years ago. Approximate diameter of 90km.

In more recent history, sources indicate that an asteroid impact may have caused the death of up to 10,000 people in the Chinese city of Qingyang in 1490[10], and an explosion generally attributed to an asteroid impact destroyed 2000km2 of Taiga close to the Tunguska River in Siberia in 1908.[11]

Supervolcanic eruption

WHAT IS AT STAKE?

The eruption of the Toba supervolcano in Indonesia, around 74,000 years ago, ejected billions of tonnes of dust and sulphates into the atmosphere[1]. Experts estimate that it caused a global cooling of 3-5°C for several years, and led to devastating loss of plant and animal life[2]. Some have argued that Toba caused the greatest mass extinction in human history, bringing our species to the brink of extinction[3].

Super-volcanic eruptions are events in which at least 400 km3 of bulk material is expelled. Eruptions of such magnitude may happen at any time in the future, with catastrophic consequences.

HOW MUCH DO WE KNOW?

In order to assess the likelihood of supervolcanic eruptions, we have to rely on a relatively limited set of past observations, which makes any estimates very uncertain[4]. Existing data suggest that a supervolcanic eruption will occur every 17,000[5] years on average – with the last known event occurring 26,500 years ago in New Zealand[6]. We are currently unable to anticipate volcanic eruptions beyond a few weeks or months in advance, but scientists are monitoring a number of areas, including Yellowstone in the US[7], which have been identified as potential sites of a future supervolcanic eruption.

The impact of a supervolcanic eruption is directly connected to the quantities of materials ejected by the volcano. Dust and ashes will kill human populations nearby and devastate local agricultural activity. In addition, the release of sulphate and ashes in the atmosphere will affect the amount of solar energy reaching the surface of the planet and may lead to temporary global cooling[8] and severe environmental effects[9].

WHAT ARE KEY FACTORS AFFECTING RISK LEVELS?

- **There is no current prospect** of reducing the probability of a supervolcanic risk, but there may be ways to mitigate its impact[10].
- **Improvements** in the ability to identify volcanoes with potential for future super-eruptions and predict eruptions will increase preparedness, and ensure that food stockpiles are available to mitigate a temporary collapse of agricultural systems.
- **Resilience building,** particularly the potential to rely on food sources less dependent on sunlight – including mushrooms, insects and bacteria – could significantly reduce the death rate among humans[11].

VOLCANIC ERUPTIONS

Volcanic eruptions are measured through a magnitude scale, a logarithmic scale, ranging from 0 to 9, where each unit increase indicates an eruption 10 times greater in erupted mass[12]. At the top of the scale, supervolcanic eruptions (M 8) release more than 400 km3 of magma. By comparison, **the largest volcano eruption recorded in human history, the 1815 Tambora eruption in Indonesia, was a magnitude of about 7: 41km3 of magma was expelled[13], claiming over 70,000 lives[14].** When Mount Vesuvius erupted in 79 AD, devastating the Roman cities of Pompeii and Herculaneum, it released approximately 4km3 of magma, placing it at magnitude 6[15]. More recently, the May 1980 eruption of Mount St. Helens in Washington, USA, with just over 0.5km3 released, was a magnitude 5.1[16].

Reviewed by
STEPHEN SPARKS

This map represents the largest recorded volcanic eruptions

Solar geoengineering

WHAT IS AT STAKE?

Two sets of emerging technologies known together as geoengineering[1] may make it possible to manipulate the atmosphere, with the potential to reduce climate risk[2].

The first set, known as carbon removal, directly removes carbon dioxide from the atmosphere, and if emissions are eventually reduced to zero, may provide a lasting solution to climate change. Most scientists now concur that some form of carbon removal will be needed to stay within the 1.5-2°C temperature rise goal set in Paris. However, of the many potential carbon removal technologies, none is currently available on the massive scale needed.

The second, known as solar geoengineering, promises to reduce the temperature of the Earth by reflecting light and heat from the sun back into space, particularly through the injection of aerosols or other particles into the stratosphere. Today, solar geoengineering only exists in computer models. The first in situ experiment in the stratosphere is currently being planned by a team of scientists at Harvard university[3]. Eventual deployment of solar geoengineering would be the most global enterprise humanity has ever undertaken, as it would affect the entire atmosphere and therefore all people – though its local impact may vary. The technology therefore poses potentially profound risks that transcend borders and raise significant ethical, socio-economic, political and governance challenges. Good governance will be a crucial part of making these technologies work as part of a comprehensive strategy to address climate change.

HOW MUCH DO WE KNOW?

According to scientists, solar geoengineering is the only known technique for quickly stopping or even reversing the rise in global temperatures. Although it does not solve the root cause of climate change, it could be used to reduce the length or the magnitude of a temperature overshoot (beyond the Paris goal) during the transition period needed for massive decarbonization at the global level, or provide insurance against a potential 'climate emergency'[4,5]. However, we don't know enough about the risks and potential benefits of the technology, and it carries considerable risks – in particular, it may destabilize local and global climate, as well as various elements of the global ecosystem. In addition, a sudden termination of solar geoengineering would lead to rapid and severe global warming, with no time for natural and social systems to adapt[6].

A complete geoengineering intervention would require considerable investment and involve drastic reduction of greenhouse gas emissions as well as removal of carbon dioxide from the atmosphere. However, according to some estimates, the direct costs of solar geoengineering only could be as low as $10 billion per year[7]. The cost is low enough that an individual country, a small group of countries, or even a wealthy individual could deploy this technology unilaterally and in an ungoverned manner, without properly taking into account the interests of others. This not only could lead to serious geopolitical tensions, but if side effects prove to be negative, it also opens the relatively close prospect of climatic chaos triggered by reckless human intervention[8].

WHAT ARE KEY FACTORS DRIVING IMPACT AND PROBABILITY?

- The window for staying within the Paris temperature goals through emissions reduction alone has most likely closed already[9] so that some level of carbon removal and/or solar

geoengineering deployment will likely be necessary, which comes with its own risks.
- Unless massive efforts on greenhouse gas reduction are urgently made, carbon removal and solar geoengineering technologies would need to be deployed on a larger scale.
- Carbon removal and solar geoengineering could present a serious moral hazard, and lead countries to avoid emission abatement[10] or encourage inaction[11].
- Better understanding of the climate system will improve our understanding of risks associated to carbon removal and solar geoengineering and may lead to considerably safer interventions[12].
- One important risk factor is the potential for hasty, ungoverned, unilateral deployment of solar geoengineering, which better frameworks for global coordination could reduce[13].

CARBON REMOVAL[14]

In order to reduce atmospheric greenhouse gas concentrations to acceptable levels, in addition to drastic emission reductions, a portion of the accumulated carbon dioxide in the atmosphere would also need to be removed and stored in a different form. Some of those solutions are already technologically feasible and adopted today – for instance, reforestation could capture some CO2 in the form of wood, which could in turn be used for construction, turning parts of the built environment into a carbon pit. However, the amount of carbon dioxide to be removed is so large that other technologies would need to be considered – none of which exist at the necessary scale. Leading contenders include “direct air capture (DAC)”, using chemical means to fix carbon dioxide and “bioenergy with carbon capture and storage (BECCS)” relying on burning biomass for electricity and immediately capturing the carbon dioxide. Other technologies are also being considered, such as enhanced weathering of rocks, increasing ocean alkalinity, ocean fertilization and various means of land management increasing the carbon content of soils. All of these technologies come with substantial environment, social and economic risks which would need to be managed in relation to the risks of other interventions, or the risks of not intervening at all.

Unlike solar geoengineering, institutional framework for addressing carbon removal exists in a number of fora, such as the UN Framework Convention on Climate Change (UNFCCC), the Convention on Biological Diversity (CBD) and the London Protocol of the London Convention (LC/LP), although there remains a great deal of work to address key governance issues. Governance challenges include establishing clear agreements between countries on responsibilities for removing the accumulated carbon from the atmosphere, developing transparent frameworks for measuring, reporting and verifying carbon removals, enhancing international cooperation for innovation, research, development and deployment of these technologies as well as agreements for their financing.

KEY MESSAGES FOR GOVERNMENTS AND CIVIL SOCIETY

1. The time for leadership is now. The governance of geoengineering must be addressed before large scale research and deployment begins. Early entrants to this discussion will play a defining role on a critical issue of global governance.
2. We need to learn more. The world does not know enough about the risks, unintended consequences and potential benefits of solar geoengineering. Well-governed research may help answer these questions and can help set the agenda on issues that matter to the community.
3. It takes a village. No one global institution can address all the dimensions of geoengineering governance. Governance must be bottom-up as well as top-down, and span processes and institutions in interconnected ways. Civil society, faith communities, the private sector, young people and others must all make their voices heard.

Artificial intelligence

WHAT IS AT STAKE?

In narrow domains, artificial intelligence (AI) systems have reached superhuman level relatively quickly – for instance, in identifying the location of a photograph or playing complex games like Jeopardy or Go. In the coming decades, there is a high probability that these systems may surpas humans in broader domains. The danger of entities more intelligent than us can be understood by considering the power we humans have drawn from being the smartest creatures on the planet. Even if the values of artificial intelligence systems can be aligned with those of their creators, they are likely to have a profound impact on socio-economic structures and geopolitical balance. But if the goals of powerful AI systems are misaligned with ours, or their architecture even mildly flawed, they might harness extreme intelligence towards purposes that turn out to be catastrophic for humanity. This is particularly concerning as most organizations developing artificial intelligence systems today focus on functionality much more than ethics.

POSSIBLE SCENARIOS[1]

Most experts agree that a superintelligent AI is likely to be designed as benevolent or neutral and is unlikely to become malevolent on its own accord. Instead, concern centers around the following two scenarios:

- **The AI is programmed** to do something devastating: autonomous weapons are AI systems that are programmed to kill. In the hands of the wrong person, these weapons could easily cause mass casualties. Moreover, an AI arms race could inadvertently lead to an AI war that also results in mass casualties. To avoid being thwarted by the enemy, these weapons would be designed to be extremely difficult to simply “turn off,” so humans could plausibly lose control of such a situation. This risk is one that is present even with narrow AI, but grows as levels of AI intelligence and autonomy increase.
- **The AI is programmed** to do something beneficial, but it develops a destructive method for achieving its goal: this can happen whenever we fail to fully align the AI’s goals with ours, which is strikingly difficult. If you ask an obedient intelligent car to take you to the airport as fast as possible, it might get you there chased by helicopters and covered in vomit, doing not what you wanted but literally what you asked for. If a superintelligent system is tasked with an ambitious societal project, it might wreak havoc as a side effect, and view human attempts to stop it as a threat to be met.

As these examples illustrate, the concern about advanced AI isn’t malevolence but competence. A super-intelligent AI will be extremely good at accomplishing its goals, and if those goals are not aligned with ours, we have a problem. You are probably not an evil ant-hater who stomps on ants out of malice, but if you are in charge of a hydroelectric green energy project and there is an anthill in the region to be flooded, too bad for the ants. A key goal of AI safety research is to never place humanity in the position of those ants.

HOW MUCH DO WE KNOW?

It is now widely accepted that we will be able to create AI systems capable of performing most tasks as well as a human at some point. According to the median surveyed expert, there is a roughly 50% chance of such AI by 2050 – with at least a 5% chance of superintelligent AI within two years after human-level AI, and a 50% chance within thirty years[2].

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The long-term social impact of human-level AI and beyond, however, is unclear, with extreme uncertainty surrounding experts' estimates.

The ability to align AI with human values is widely considered to be important in determining the risk factor. However, aside from the open question of which values to select, there are important unsolved technical problems regarding how to make an AI understand human goals, making an AI adopt these goals, and ensuring that it retains these goals if it recursively self-improves.

WHAT ARE KEY FACTORS IMPACTING RISK LEVELS?

- **AI risk is still emerging today,** but could rapidly accelerate if sudden technological breakthroughs left inadequate time for social and political institutions to adjust risk management mechanisms. If AI development gets automated, in particular, new capabilities might evolve extremely quickly.
- **Risks can be exacerbated** by geopolitical tensions leading to an AI weapons race, AI development races that cut corners on safety, or ineffective governance of powerful AI.
- **The level of AI risk** will partly depend on the possibility to align the goals of advanced AI with human values – which will require more precise specification of human values and/or novel methods by which AIs can effectively learn and retain those values.

WHAT IS ARTIFICIAL INTELLIGENCE?

AI is non-biological intelligence – more specifically, technology that enables machines to accomplish complex goals. One typically distinguishes between weak/narrow AI, designed and trained for a particular task such as spam filters, self-driving cars or Facebook's newsfeed, and general AI or Artificial General Intelligence (AGI), which is able to find a solution when presented with an unfamiliar task, with human-level ability or beyond.

The current quest for AGI builds on the capacity for a system to automate predictive analysis – a process generally described as machine learning. One important element of machine learning is the use of neural networks: systems that involve a large number of processors operating in parallel and arranged in tiers. The first tier receives a raw input, and each successive tier receives the output from the tier preceding it. Neural networks adapt and modify themselves autonomously, according to initial training and input of data, in ways that are typically not transparent to the engineers developing them.

If researchers one day succeed in building a human-level AGI, it will probably include expert systems, natural language processing and machine vision as well as mimicking cognitive functions that we today associate with a human mind, e.g., learning, reasoning, problem solving, and self-correction. However, the underlying mechanisms may differ considerably from those happening in the human brain just as the workings of today's airplanes differ from those of birds[3].

Reviewed by
ROEY TZEZANA

Unknown risks

WHAT IS AT STAKE?

In 1900, forty-five years before the first nuclear bomb exploded, very few could have predicted that atomic energy would be one of the main potential causes of global catastrophe. Climate change is now broadly regarded as an urgent global concern, but when the United Nations was established in 1945, it was very far from public attention. Rapid economic, scientific and technological development – which seems set to continue in the 21st century – brings unforeseen new risks in its wake. It is therefore likely that many future global catastrophic risks are at present unknown.

HOW MUCH DO WE KNOW?

There is obviously little that we know about unknown risks, but we do have the capacity to develop better methods for scanning and monitoring them.

Some risks independent from human action, mostly connected to distant cosmic forces, are currently assigned such a low probability that we chose to leave them outside of this report. For instance, if the Earth found itself in the direct path of a gamma ray burst from a distant star, this could result in a mass extinction event, but there is no clear trace of such an event ever occurring, and the risk remains theoretical[1]. Scientific progress may lead us to reconsider the likelihood and expected impact of certain natural risks and bring new ones to our awareness.

As for risks resulting from human activity, they will most likely be related to new technologies and their interaction with existing social and natural systems. We cannot foresee what these risks will be in advance, but we can closely monitor scientific and technological breakthroughs, and assess what their potential impact may be, in order to take appropriate measures in advance.

WHAT ARE KEY FACTORS AFFECTING RISK LEVELS?

- **A fast rate of technological change** increases the chances of a risk rising to global concern before proper governance mechanisms can be put in place. Conversely, foresight work will support our ability to prepare for new risks in advance.
- **The probability and impact** of unknown risks correlates with the overall fragility of our societies, which in turn depends on the state of our environment, the availability of new technologies, and global governance systems in place.

NANOTECHNOLOGY – A NEW EMERGING RISK?

Our capacity to manipulate matter on the nano-scale has made it possible to manufacture materials engineered at the molecular level. These new products display remarkable characteristics and have the potential to address pressing human needs at low cost[2]. Research on nanotechnology shows promise in a range of fields. Nanomedicine could help detect and destroy cancerous tumors more effectively[3] and has the potential to significantly extend healthy lifespans[4]. New solar cells and batteries based on nano-particles could be many times more efficient than those available at present and revolutionize renewable energy production[5]. Nano-materials could exhibit unique capabilities: nano-fibers could also be used as sensors, to create clothing that monitors the wearer's health, or conjoined with nano-particles that prevent the growth of bacteria and eliminate bad smells. The strongest nano-materials like carbon nanotubes could be used to create structures that are extremely lightweight and yet highly strong and durable.

However, we know very little about associated risks. Studies have shown potential side-effects on health associated to the inhalation or ingestion of nano-particles[6], though very little is known as to potential broader impact on public health or the risk of large-scale pollution[7]. Nano-technology also now raises significant concerns as to the possibility of large-scale surveillance through networks of microscopic sensors and robots – a technology generally referred to as 'smart dust'. Research on risks associated with nanotechnology and development of global governance frameworks in par with development of the technology itself will reduce the chances that materials with high potential impact on human health and the environment get into circulation[8].

Part 2

Governing the risk

Governance of nuclear weapons

States currently manage the risks of nuclear weapons through a range of measures that, together, have prevented the worldwide spread of these weapons of mass destruction, but have not significantly reduced the risk of catastrophic use.

The pillar of nuclear military strategy is deterrence, whereby nuclear-armed states threaten to retaliate against other states' use of nuclear weapons against them. This doctrine is considered by some to be an effective way of preventing nuclear war. The fact that no nuclear weapons have been used in any conflict since 1945, however, suggests that an emerging moral norm may also play a role in discouraging their use.

International cooperation, beginning with the 1963 US-Soviet treaty to ban atmospheric testing, along with subsequent US-Soviet/Russian bilateral treaties and agreements has reduced and stabilized nuclear arsenals from a high of 68,000 in the late 1980s to about 15,000 today. In addition, the 1970 Nuclear Non-proliferation Treaty (NPT) has prevented the development of nuclear weapons in all countries beyond the original five (United States, Soviet Union/Russia, United Kingdom, France and China) with the exception of India, Pakistan, North Korea, and probably Israel. Altogether, some 25 governments have given up their nuclear weapons programs, including South Africa, Libya, Belarus, Kazakhstan, and Ukraine. Another 15, like Canada, Brazil, and Argentina, have contemplated programs but not embarked on them, in keeping with their responsibilities under the NPT.

The UN Security Council, whose permanent members include the five recognized nuclear weapons states, enforces the Nuclear Non-proliferation Treaty in partnership with the International Atomic Energy Agency (IAEA). Although the IAEA was established primarily to promote and oversee the development of civilian nuclear power, under Article III of the NPT, the IAEA is entrusted with verifying adherence to the Treaty. Parties to the NPT regularly report to the IAEA about the means used to safeguard and secure enriched uranium and plutonium used in civilian power plants, as well as steps to prevent the use of nuclear materials for bombs.

Several states have not complied with their NPT obligations and faced penalties from the international community. Iraq embarked on a nuclear weapons program, but after nuclear bomb technology was discovered in 1991, the program was destroyed by a special UN Security Council-mandated force. In the case of Iran, international economic sanctions were applied when suspicions arose about its possible pursuit of nuclear weapons. To prevent Iran from acquiring them, multilateral negotiations produced the 2015 Joint Comprehensive Plan of Action. It mandated reduction of the means to enrich uranium to a minimal level and only allowed enrichment to below weapons-grade. It also ensures continuous monitoring by the IAEA of Iran's civilian nuclear program.

The difficulties of enforcing the NPT when countries do not wish to cooperate, however, are illustrated by the case of North Korea, which announced its withdrawal from the NPT in 2003. It has since conducted at least six nuclear weapons tests. Despite international pressure, including economic sanctions, North Korea continues its nuclear program in the belief that it will deter aggression by the United States.

The fact that decisions about nuclear weapons are made in utmost secrecy, outside of democratic policy processes, poses substantial obstacles to nuclear

Reviewed by
AMBASSADOR NOBUYASU ABE

governance in the public interest. Yet citizen protests in the United States, Europe and Japan from the 1950s through the 1980s have raised awareness of the risks and pressured governments to curtail nuclear weapons programs. For example, mass protests in the 1980s by the European Campaign for Nuclear Disarmament and the US Freeze movement pressured political leaders in Europe, the Soviet Union and the United States to enact major reductions in nuclear arsenals and, some even suggest, contributed to the end of the Cold War.

Recently, an international humanitarian movement worked with non-nuclear weapons states to introduce a UN treaty banning all nuclear weapons. One hundred and thirty-five of the 193 member countries participated in the 2017 UN treaty negotiations; 122 countries voted in favour of the final treaty, one against, and one country abstained. As of April 2018, 54 countries have signed the treaty and seven have ratified it, adapting their national legislation to comply with its provisions. The treaty, which is indefinitely open for signing, will take effect when 50 nations have ratified it. Not since the Nuclear Non-proliferation Treaty of 1970 have states taken such dramatic and collective action to prohibit possession of nuclear arsenals.

At the same time, unfortunately, re-emerging nationalism is spurring the nine nuclear weapons states – none of which participated in or voted on the UN ban treaty – to redesign, increase and, in some cases, lower the threshold to use their nuclear weapons. Such actions reinforce beliefs about the purported utility of nuclear weapons, undermine international cooperative efforts to reduce the risks, and increase the probability of catastrophic nuclear war.

KENNETTE BENEDICT
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Governance of chemical and biological weapons

Biological and chemical weapons are banned by two international treaties: the Biological Weapons Convention (BWC) of 1975, with 178 State Parties, and the Chemical Weapons Convention (CWC) of 1997, with 189 State Parties. In both cases, dual-use creates a particular difficulty: the same chemicals and biological agents can be applied for beneficial purposes, or serve as the core components of deadly weapons.

The CWC, negotiated with participation of the chemical industry, defines a chemical weapon by its intended purpose, rather than lethality or quantity. It allows for stringent verification of compliance: acceding to the CWC means mandatory destruction of all declared chemical weapons as well as their production sites – to be subsequently verified by appointed inspectors.

The BWC is less prescriptive, which results in ambiguities and loopholes. Research is permitted under the Convention, but it is difficult to tell the difference between legitimate and potentially harmful biological research. States are required to "destroy or to divert to peaceful purposes" their biological weapons, but no agreed definition of a biological weapon exists. In addition, there is no secretariat to monitor and enforce implementation, except for a small support unit in Geneva, and no mechanism exists to verify destruction or diversion, despite efforts since 1991 to include legally-binding verification procedures in the BWC. Some lesser steps have been taken, including confidence-building measures on which State Parties are to report each April, and management standards on biosafety and biosecurity, but implementation is voluntary.

Under the BWC, complaints can be lodged with the UN Security Council – which can investigate them – but no complaint has ever been made, and enforcement mechanisms do not exist. The CWC includes a provision for "challenge inspections" in case of suspected chemical weapons use – but again, it has never been invoked, not even in the case of Syria, though doubts about a chemical weapons program are regularly debated at the Security Council. Over the last three and a half years, 28 visits by the "Declaration Assessment Team" have not been able to clarify discrepancies and determine if Syria's declaration is accurate and complete. Additionally, the security context and shifting territorial control present significant challenges in ensuring that prohibition is fully implemented within the country. In case of alleged use of chemical or biological weapons in countries not party to the conventions – like Syria in 2013 – investigations can be requested through the UN Secretary-General's Mechanism for Investigation of Alleged Use of Chemical and Biological Weapons, concluded in 1988.

Only four UN countries are not State Parties to the CWC (Egypt, Israel, North Korea and South Sudan). The highest concern among those is North Korea, said to possess large quantities of chemical weapons which could be sold or traded to unscrupulous non-State actors. It also needs to be mentioned that neither the United States nor Russia have destroyed their large chemical arsenal, due to the cost and environmental challenges of chemical disposal. Both countries requested extensions of the deadlines imposed by the Organisation for the Prohibition of Chemical Weapons, yet the existence of large stocks remain a risk.

In the 55 years since the BWC was negotiated, rapid advances in biotechnology have been made, which challenge our current governance models. The pharmaceutical and medical industries possess the tools and knowledge to develop biological weapons, and the Internet spreads this know-how to those who might use it for nefarious purposes. Biological threats do not respect borders and, as global travel increases, could quickly have a regional or even global impact. Terrorists could contaminate the water supply or release deadly bacteria, but it is also possible that the lack of lab safety could result in the inadvertent release of a virus or disease. The first step towards a solution would be to acknowledge the seriousness of the situation. But leadership is also needed to place this issue at the right place on the global agenda, and may come from the UN Security Council, the G7 or the G20, coalitions of government and industry bodies, civil society groups, or one or more nations acting as global champions.

ANGELA KANE

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Governance of catastrophic climate change

The challenge of climate change has been defined as a 'super-wicked' problem. It needs urgent responses. It needs those responsible to accept responsibility, and provide solutions and support. It requires aspects of sovereignty to be ceded to an international body, or that wide-ranging powers be conferred to a central body at the national level. And it carries perverse incentives to push action into the future[1].

Despite these complexities, international negotiations to address the challenge of climate change have been underway since the UN Conference on Environment and Development at Rio in 1992, and under the aegis of the UN Framework Convention on Climate Change (UNFCCC) since 1994. The first protocol on climate change – the Kyoto Protocol – was adopted at the third Conference of the Parties (COP) to the UNFCCC in 1997. Since then, negotiations have continuously evolved to culminate in the Paris Agreement at the 21st COP in December 2015.

The task of comprehensively assessing the relevant science was given to the Inter-governmental Panel on Climate Change (IPCC). IPCC's first assessment report was published in 1990, and it has since been regularly assessing the growing body of literature on impacts, vulnerability and mitigation options for climate change. Governments have a key role in nominating authors and approving texts. These assessments have had a key influence on the global negotiation processes.

Scientific assessments undertaken by IPCC have emphasised the need to limit global average temperature increase to below 2°C, but also covered a range of likely scenarios up to a 6°C increase and beyond. Political negotiations, however, have consistently disregarded the high-end scenarios that could lead to abrupt, irreversible or runaway climate change. This was despite scientific evidence that risks associated with tipping points "increase disproportionately as temperature increases between 1–2°C additional warming and become high above 3°C"[2].

Thus, in the lead up to and during the Paris negotiations, the need-based focus was on ensuring that temperature increases "remained well below 2°C"[3]. However,

Reviewed by
OWEN GAFFNEY

A GLOBAL CARBON LAW ROADMAP TO MAKE PARIS GOALS A REALITY[4]

The Paris Agreement on climate commits countries to take action to keep global average temperature "well below 2°C above pre-industrial levels and to pursue efforts to limit the temperature increase even further to 1.5°C".

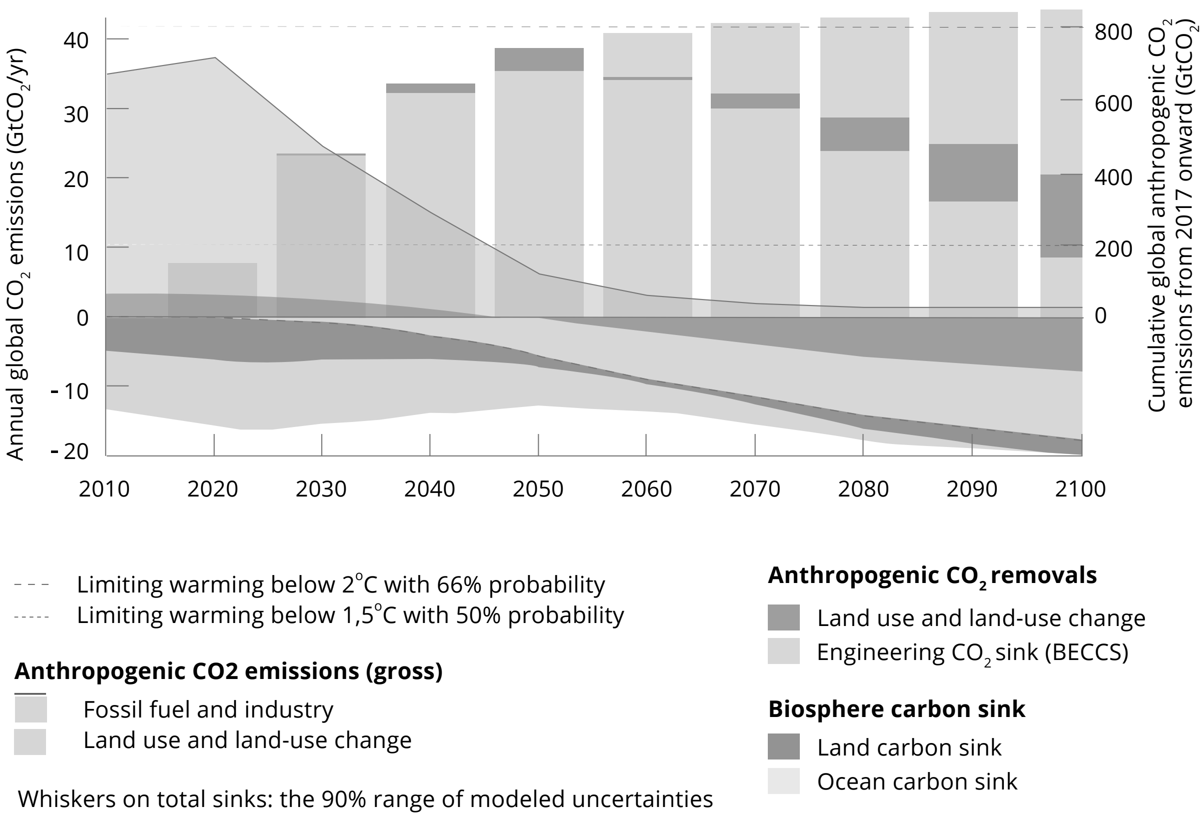
To aim for the 1.5°C target, the total carbon dioxide that can be emitted in humanity's remaining time on Earth – known as the carbon budget – is small. For a mere 50% chance of hitting this target, the carbon budget left from 2020 onwards is just 400 billion tonnes (Gt) of carbon dioxide[5].

If we were to consider a higher target, for a 66% chance of keeping global temperatures below 2°C, from 2020 onwards, the world has a remaining carbon budget of 680 Gt of carbon dioxide that it can emit[6] – although more recent updates suggest the budget for that target could be higher, so that reaching this target could be within our grasp with immediate action on an unprecedented scale[7].

The world currently emits over 400 Gt of carbon dioxide every decade, so it is likely the world will overshoot the 1.5°C target. Therefore, in addition to reducing emissions to around zero, the world will need to draw carbon dioxide out of the atmosphere at scale in order to meet the Paris Agreement. This requires immediate, massive, globally-coordinated action.

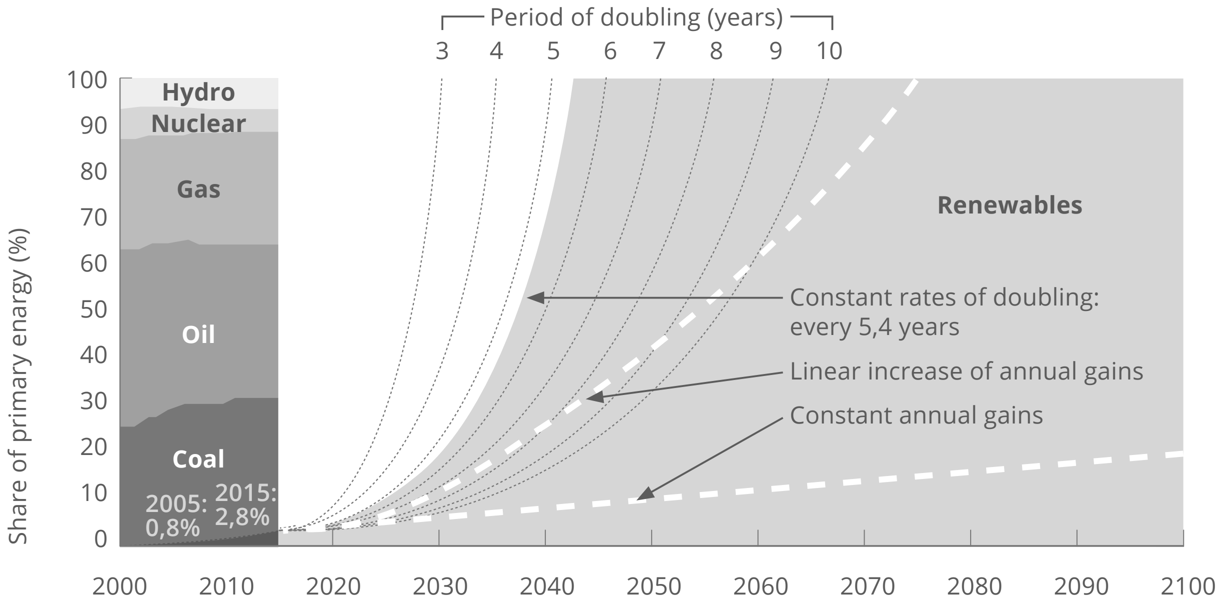
In 2017, an international team of researchers developed and published a roadmap for rapid decarbonisation that reduces the risk of Earth passing the 2°C threshold. The analysis can be summarised as a "Carbon Law", a rule of thumb analogous to Moore's Law in the IT sector, of halving emissions every decade to approach zero by 2050 or 2060, turn carbon sources to sinks and develop new carbon sinks. This is explained in the graph below. The next stage in the roadmap development will be launched at the Global Climate Action Summit in San Francisco in September 2018.

Decarbonization pathway consistent with the Paris agreement



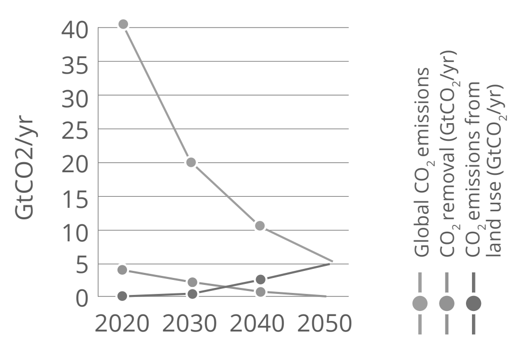
FOSSIL FUEL PHASE OUT[8]

Globally, primary energy installation has been doubling in capacity every 5-6 years for a decade. If this doubling pace continues, the world will be 100% powered by renewables by 2050. We need to go beyond linear thinking to think exponentially about the carbon challenge.



GLOBAL CARBON LAW GUIDING DECADAL PATHWAYS[9]

The three components of the Carbon Law: halve fossil fuel emissions every decade, reduce land-use related emissions, ramp up carbon storage solutions.



pessimism relating to the actual ability to conform to the 2°C trajectory could have led to modest pledges and delays in mitigation efforts, implying exponentially higher costs of subsequent adaptation actions. Paradoxically, on the assumption that the world would limit temperature increases to 2°C, the Paris Agreement is nowhere close to the ambition required on adaptation and resilience building. As such, despite the fact that the current pathways offer a very high probability of exceeding the 2°C guardrail, the world is currently completely unprepared to envisage, and even less deal with, the consequences of catastrophic climate change.

The Sendai Framework for Disaster Risk Reduction (2015-2030), which was the outcome of inter-governmental negotiations supported by the UN Office for Disaster Risk Reduction at the behest of the UN General Assembly, adopted in March 2015, could have addressed itself specifically to the risks emanating not just from the aspirational 2°C scenario but the almost equally likely scenario of tending towards a 3°C to 4°C world. Instead, it generically limited itself to be “within the mandate of the United Nations Framework Convention on Climate Change under the competences of the Parties to the Convention”.

The Paris Agreement came into force in October 2016, with national pledges falling woefully short – setting the world on a 3.4°C temperature increase track[11]. Although climate change action has now become part of mainstream economic and social strategies in most countries, the United States has since withdrawn from the Climate Agreement. Not only does this greatly increase the burden of responsibility on other countries but also substantially reduces the funding for climate initiatives, thereby further increasing the risk of catastrophic climate change. In this context, the world needs to pay a lot more attention to adaptation measures than was already called for!

CLIMATE CHANGE SCENARIOS

One central method to assess the expected increase of average global temperatures is the development of climate change scenarios. Those scenarios are descriptions of alternative futures, where total greenhouse gas emissions and the resulting global temperature increase are projected on the basis of various socio-economic factors affecting emission levels, including population growth, economic activity, technological change, as well as governance and cultural values. These scenarios typically compare the anticipated effects of various parameters – particularly the anticipated effects of various changes in policy settings – with a ‘business-as-usual’ situation, and play an important part in both policy development and climate change negotiations, on a national and global level[10].

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Governance of ecological collapse

Contemporary ecological risks are increasingly global in scale, scope, and impact with strong levels of interconnection not only across the borders of nations, but across continents[1]. Action to address them, however, has to be taken at both global and national level. The environment is a classic common good: all benefit from healthy ecosystems and a pollution-free planet, while extraction of natural resources and pollution by some compromise the benefit for many.

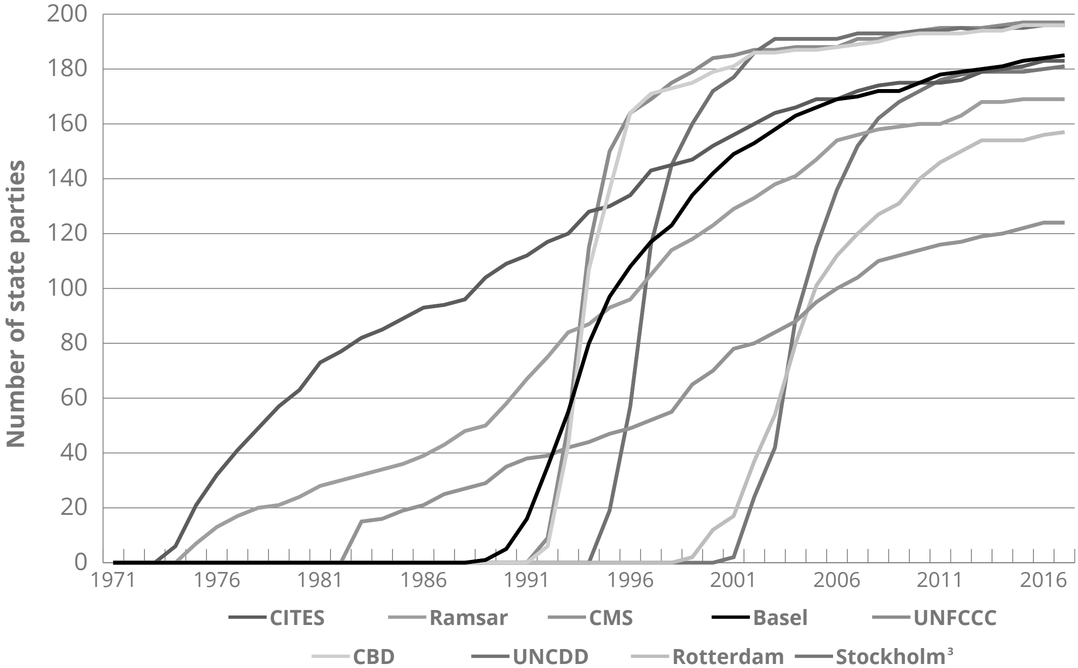
A number of international institutions oversee monitoring, assessment, and reporting on problem identification and implementation; they set standards, policies, and laws; and they support the development of institutional capacity to address existing and emerging problems at the national level. Governments crafted the institutional architecture for managing global ecological risks in the 1970s with the creation of the anchor institution for the global environment: the United Nations Environment Program, now known as UN Environment. Global environmental conventions, also known as treaties or agreements, are the main international legal instrument for promoting collective action toward managing ecological risk and staying within the safe planetary operating space. Their number and membership has increased dramatically.

About a dozen international treaties deal with global issues including climate change, land-system change, biosphere change, and chemicals and waste. These include the UN conventions on climate change, biodiversity, migratory species, trade in endangered species, desertification, persistent organic pollutants, among others. The expectation is that when countries implement their obligations under the treaties, the problems will be managed and ultimately resolved. At the national level, governments have established ministries and authorities to deal with environmental concerns, advocate for ecologically informed decision making, and improve national capacity.

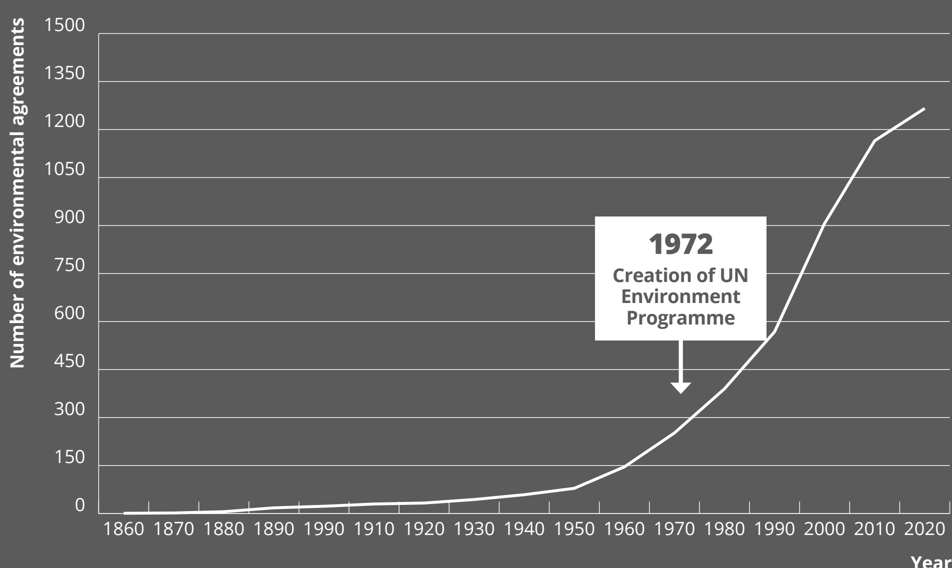
States voluntarily create international agreements to govern their relations through legal responsibilities. There is, however, no overarching judicial system or a coercive penal system that could ensure effective enforcement of the agreements that deal with environmental issues. Breaches cannot be sanctioned. Compliance and implementation have to be enticed rather than coerced. Environmental agreements such as the 2015 Paris Agreement, for example, are explicitly non-punitive: countries face no penalties for not meeting their commitments. Rather, they are facilitative, as international institutions commit to support compliance and implementation.

Importantly, many countries are implementing their obligations. The Environmental Conventions Index developed by the team at the Center for Governance and Sustainability at the University of Massachusetts Boston measures the implementation of global environmental conventions. The Index is a composite score based on the national reports that member states submit to each convention secretariat and illustrates trends across countries, within countries (across issues and over time), and across the conventions. It highlights the leaders and the laggards and raises questions about the

MEMBERSHIP TO GLOBAL ENVIRONMENTAL CONVENTIONS[2]



HISTORICAL EVOLUTION OF THE NUMBER OF INTERNATIONAL ENVIRONMENTAL AGREEMENTS[4]



determinants of implementation. Availability of data, comprehensive regulations, national capacities, cooperation, and funding emerge as important factors.

Reporting is the fundamental mechanism to entice and monitor implementation. National reports on progress in achieving global commitments are part of every agreement. Reporting, however, is a challenge because of low capacity and poor data in countries, an inadequate reporting system that does not always cover the comprehensive nature of the issues, and lack of analysis of and feedback on submitted reports. It is notable, however, that the complexity of the reporting process is not necessarily a deterrent to reporting compliance. The Ramsar Convention on wetlands, for example, requires countries to report on over 100 indicators and has among the highest reporting rates with member states reporting at close to 90% of the time.

Enforcement mechanisms do not guarantee that international commitments will be implemented, and much less that problems will be solved. Countries, however, care about reputation and can be influenced by ratings and rankings, an approach to global performance assessment that has come to be known as scorecard diplomacy.[5] This form of soft power can shape national policies and outcomes as it goes beyond 'naming and shaming' to 'naming and acclaiming'. It outlines actions that could lead to better ranking, and enables learning across peers. Scorecard diplomacy has proven effective in national governance, corruption, human trafficking, environmental democracy, and environmental performance.[6]

In the run up to the 2015 Paris Agreement, the narrative around climate change changed from a story of sacrifice to a story of opportunity. Companies, cities, and countries saw the transformation to a low carbon economy as desirable, inevitable, and irrevocable and pledged to lead it. By embracing the challenge of environmental preservation as an opportunity for the future, institutions and individuals could support effective implementation of ambitious proposals and create a community of change agents around the globe.

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Governance of pandemics

The World Health Organisation (WHO), established in 1948 as a specialised agency of the United Nations, is currently the global body in charge of governing the risk of pandemics. It does this mainly through a governance mechanism called the International Health Regulations (IHR), the goal of which is to stop public health events that have the potential to spread internationally with minimal interference of travel and trade. The IHR first came into force in 1969, with an initial focus on four infectious diseases – Cholera, Plague, Yellow Fever and Smallpox.

Revised in 2005, the IHR now acknowledge that many more diseases than the four originally covered may spread internationally, and that many cannot be stopped at international borders, as was demonstrated by the spread of HIV in the 1980s and SARS in 2003. Emphasis is therefore placed now on the requirement that countries rapidly detect and respond to outbreaks and other public health events with potential to spread internationally. The revised version of the IHR also includes a global safety mechanism that calls for collaborative action should a public health event be assessed as at risk of spreading internationally.

The governance of pandemics typically involves collaboration between the WHO, ministries of health and public health institutions. Some nations have established Centres for Disease Control (CDC) whose role is to monitor transmissible public health events. Some of those, including the US CDC and Public Health England, provide international support to developing countries, helping them strengthen their capacity to better detect and respond to public health events. When an outbreak occurs, other national institutions, hospitals in particular, play a major role in early detection and containment.

The IHR are a binding agreement under international law, and as such provide a framework for national legislation and responsible national and international action. But like all international law and treaties, there is no enforcement mechanism. Under the IHR, countries are required to strengthen eight core capacities in public health that are deemed necessary for rapid detection of and response to a disease outbreak. Each year countries are required to do a self-assessment of their core public health capacity, and to report the outcome of their assessment to the WHO. However, there is no sanction for non-reporting, and many countries do not report. As part of the IHR (2005) Monitoring and Evaluation Framework, the Joint External Evaluation (JEE) was developed as a mechanism where a country's core capacity in public health is assessed by a group of international experts. All countries may request such an evaluation through the WHO on a voluntary basis. The tool was made available in 2016 and to date, over 79 countries have done so.

The revised IHR provide a decision tree which can be used by countries to determine whether a public health event in their country has the potential for international spread, and should therefore be reported as a potential public health emergency of international importance (PHEIC). The WHO Director General then conducts a risk assessment. For this, they can ask for a recommendation from an emergency committee set up under the auspices of the IHR, and/or from other experts from around the world. If the Director General decides that the event is a PHEIC, the WHO must provide emergency recommendations aimed at curbing international spread, and review those recommendations every three months until the PHEIC has been declared over.

After the recent Ebola outbreak in West Africa, an external review of the revised IHR was conducted, and recommendations from that review are now being considered by the World Health Assembly of the WHO.

DAVID HEYMANN

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Governance of asteroid impact

There is currently a worldwide effort underway to search the sky for Near-Earth Objects (NEOs). While the bulk of discoveries are made by ground-based telescopes funded by the US National Aeronautics and Space Administration (NASA) and operated in the United States, other recent discovery sites include Morocco, Brazil, China and Japan. After an object is discovered, follow up observations undertaken by dozens of observatories around the world are collected to perform precise orbital calculations, which in turn allows analysis to quantify the risk. Should an impact be predicted with sufficient warning time, several techniques are being studied (both by the NASA Planetary Defense Coordination Office and the European Union's NEOShield-2 project) that may allow successful deflection of an object away from an impacting trajectory. Even if an impact is imminent, evacuation of the impact zone would allow people to escape harm if they are able to move a sufficient distance, and if the size of the object is such that only local damage is expected.

NASA is a signatory to the International Asteroid Warning Network (or IAWN), and as such part of a United Nations-endorsed effort established through the work of the Committee on the Peaceful Uses of Outer Space (COPUOS) that currently includes at least 10 different efforts around the world focusing on asteroid defense, communication, and education. Membership in the IAWN is non-binding and voluntary but it enables data to be collected worldwide, consolidated and analyzed, and the resulting information is released to all UN COPUOS member states.

The United States Congress has directed NASA to find at least 90% of all asteroids larger than 140 meters whose orbits could lead to an impact with Earth. NASA funds several survey teams in the United States specifically to search for asteroids. NASA also funds the Minor Planet Center, which serves as an international clearing house for asteroid-related data, as well as the JPL Center

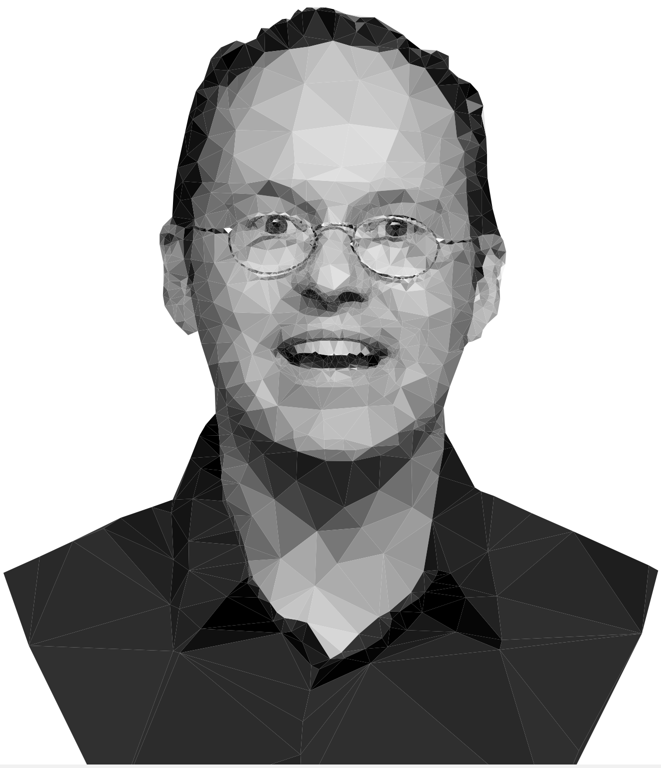
On the basis of historical evidence, an asteroid impact large enough to cause a global catastrophe is estimated likely to occur every

120,000 YEARS

for NEO Studies, which computes high-precision orbits and evaluates the impact hazard from each object. NASA requires, as a condition for continued funding, that all data and data products from asteroid surveys and orbit computations be made available in the public domain.

In other countries, surveys often operate on a voluntary basis, with no binding mechanism to force data submission to the MPC. However, as the MPC is currently recognized as the worldwide clearing house for asteroid data, and on the basis of the International Astronomical Union's rules for asteroid naming rights, the desire of all individuals involved in contributing to the inventory of NEOs tends to drive them to submit data for publication.

In the field of NEO discovery and tracking, there are few if any non-formal mechanisms in place. A few mailing lists support discussion of the subject, as well as occasional meetings bringing together members of the professional community with enthusiast astronomers. The latter, often unpaid amateurs, through the supply of observations, support the research conducted mainly by professional astronomers in the United States and, to a somewhat lesser extent, in Europe.



TIM SPAHR

CEO of NEO Sciences, LLC, former Director of the Minor Planetary Center, Harvard-Smithsonian Center for Astrophysics

Governance of global catastrophic volcanic eruption

Monitoring volcanoes is largely a responsibility of national institutions that operate Volcano Observatories, and work with political authorities, civil protection agencies and communities to manage the risk. Over the past century, these institutions have been set up in many countries to monitor either a single volcano or multiple volcanoes: the World Organisation of Volcano Observatories lists 80 Volcano Observatories in 33 countries and regions, and plays a coordinating role among them. In countries with infrequent eruptions and no Volcano Observatory, national institutions responsible for natural hazards would be responsible for monitoring the risk.

On an international scale, bilateral and multilateral agreements support scientific investigation and volcanic risk management. These commonly involve developed nations (e.g. France, Italy, Japan, New Zealand, UK and USA) supporting developing nations. In particular, the Volcano Disaster Assistance Program of the US Geological Survey and the U.S. Agency for International Development provide global support to developing nations through training, donations of monitoring equipment and assistance in responding to volcanic emergencies at the invitation of governments. In addition, an international network of nine Volcanic Ash Advisory Centres issues warnings of volcanic ash eruptions into the atmosphere to protect aviation, with world-wide coverage. Apart from those, there is no organization or institution that has a mandate to manage volcanic risk on a global scale.

More informal global coordination is achieved through voluntary international and regional organizations, networks and projects that coordinate the sharing of scientific knowledge, technical expertise and best practice. The International Association of Volcanology and Chemistry of the Earth's Interior (IAVCEI) is the main scientific organization for volcanology with a membership of over 1000, consisting both of academics and Volcano Observatory staff. IAVCEI co-ordinates international commissions and working groups on many issues related to volcanic risk management. These activities are voluntary, so the coverage of key issues on volcanic risk and its governance can be uneven.

Although super-eruptions are very infrequent (an estimated event every 17,000 years), seen through the lens of deep geological time they are rather common, and so humanity will eventually experience one. Volcanoes with potential for future super-eruptions either have a past record of super-eruptions or have been long dormant. Known sites include volcanoes in the USA, Japan, New Zealand, Turkey and several south American countries, but identifying potential future sites of eruptions with no previous record is significantly more challenging.

The existing system provides an effective, though imperfect, structure to manage local volcanic risk. Depending on the magnitude of the event, the system is likely to come under pressure and prove inadequate in the event of a catastrophic eruption with global reach. No organisation has a specific mandate to address risk from super-eruptions. If one occurred in a populated location, we could anticipate an immediate major humanitarian crisis, with overwhelmed institutions and services, and long term effects on the environment, climate, critical infrastructure, food security and global trade. Developing a global response plan under the auspices of a UN agency and IAVCEI would be a good start to improve governance of this global risk.

A recent synthesis of global volcanic risk and its governance can be found in note (17).

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Governance of solar geoengineering

There is at present no single unified governance framework to manage risks associated with solar geoengineering, nor is there a set of interrelated elements from different governance frameworks which, together, would be able to comprehensively manage the risk. More importantly, there are no frameworks at national or international levels where the risks of solar geoengineering could be addressed together with those of other climate interventions, such as mitigation, adaptation and carbon removal, as well as the risks of non-action, such as continued high emissions of greenhouse gases.

For solar geoengineering most of the governance elements have transboundary and intergenerational dimensions, thus international and multilateral arrangements will be key[1]. Who will decide whether or not to deploy solar geoengineering, and when should such decision be made? What institution will control the global thermostat and ensure sustained deployment without sudden termination?

Two cases of existing governance at international levels are relevant to geoengineering: the Convention on Biological Diversity (CBD) and the London Protocol of the London Convention (LC/LP). Both can provide bases on which further governance can evolve.

A series of decisions taken by the Parties to the CBD provide broad guidance for addressing geoengineering. Building on a 2008 decision (IX/16 C) that limited use of ocean fertilization, CBD parties established a non-legally binding agreement in 2010 that provides guidance to Parties in limiting all large-scale climate engineering activities that may affect biodiversity until such time that science-based, global, transparent, and effective global governance mechanisms are developed (decision X/33). This decision was reconfirmed in 2016 at the Cancun meeting of the Conference of the Parties in decision (XIII/14), which specifically added the application of a precautionary approach and suggested the need for cross-institutional and transdisciplinary research and knowledge-sharing.

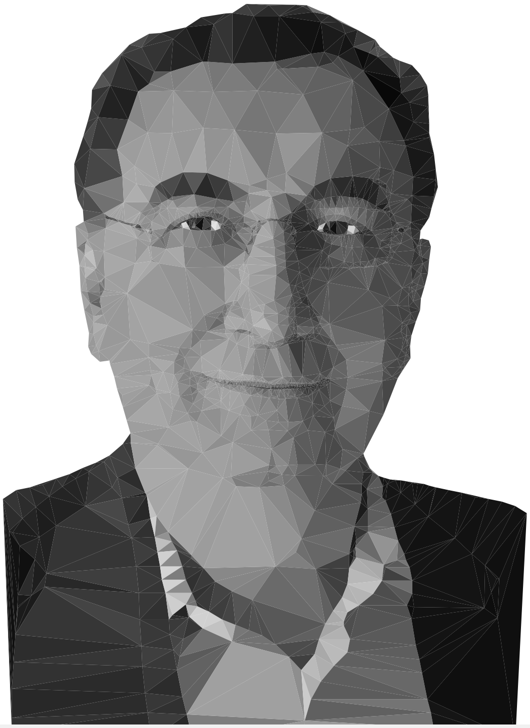
In parallel, the London Protocol to the London Convention on Ocean Dumping was amended in 2013 to create non-legally binding guidelines to assess proposals for geoengineering research in the ocean. The amendments provide criteria for assessment of such proposals and set up a stringent and detailed risk assessment framework. This framework could also be used to address some aspects of solar geoengineering.

Decisions of Parties to conventions like the CBD or the LC/LP are non-legally binding on the Parties that have ratified the convention. There are usual reporting requirements under each of the treaties, and implementation is monitored through the regular reports prepared by the Parties. There are, however, no sanctions for lack of compliance.

Risks associated to geoengineering have not yet been broadly adopted in international forums or civil society to the same extent that climate change has, although some researchers have been developing voluntary codes of conduct for research, such as, the Geoengineering Research Governance Project at the University of Calgary[2]. It is, however, still unclear what exact formats the global governance of geoengineering risk will take.

In the meantime, it is necessary that different intergovernmental fora begin or intensify their work to address the governance of solar geoengineering according to their respective mandates, in particular the UN Environment Assembly (UNEA), the UNFCCC, the CBD and the UN General Assembly. It is essential that nation states agree not to deploy solar geoengineering unless the risks and potential benefits are sufficiently known and the necessary governance frameworks are agreed upon. This, however, would require considerable learning processes, including society-wide discussions on the risks and potential benefits – which have not yet taken place.

At present, the majority of international civil society organizations focusing on climate have not addressed the issue of solar geoengineering out of concern for the perceived moral hazard that doing so might weaken political will for the emission reductions that are the essential first step for any credible response to climate change. This situation may change as climate impacts continue to mount and the serious insufficiency of existing emission reduction efforts becomes ever clearer.



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Governance of Artificial Intelligence risk

Until recently, advanced artificial intelligence was still thought of as science fiction. As such, researchers in industry, academia, and government were more concerned with simply making it work. Only in the last few years, as AI has become more advanced and commonplace, have more people considered the possible risks of advanced AI.

Since the general perception is that human-level AI is at least decades away, there has been relatively little action planning for it. However, the timelines are uncertain. Meanwhile, the problem of controlling or aligning very advanced AI with human goals is extremely difficult and may require decades to solve, motivating current research on the problem. In the shorter term, current or near-future AI also poses less extreme threats — for example in warfare, finance, cybersecurity, and political institutions, threatening privacy, employment, and income equality — that need to be managed now and will only increase in magnitude.

Such concerns are currently managed by the many existing laws and institutions that apply to particular fields where AI plays a role. However, governance of AI will present a unique challenge requiring special consideration, some of it on a short timescale. A particular and timely issue concerns AI systems deliberately designed to kill or destroy, a.k.a. “Lethal Autonomous Weapons Systems” (LAWS). LAWS are more likely to be used offensively, rather than defensively, and an arms race could be highly destabilizing or have strong undesired side-effects such as empowering terrorists and other non-state actors. There is ongoing debate and formal United Nations discussion regarding the use of international agreements to curtail LAWS development and deployment, supported by thousands of AI researchers.[1]

In fact, various actions by AI researchers in academia and industry – from signing open letters that oppose autonomous weapons to boycotting universities that pursue AI weapons research – have helped motivate governments at local and federal levels to take a stance on autonomous weapons, with 26 countries supporting an outright ban on LAWS at the time of writing this text. These efforts were boosted in late 2017 when FLI released its popular video, Slaughterbots, which introduced the public to some of the greatest threats posed by LAWS.

Another major issue coming onto the radar is that of automation and potential resulting large-scale economic impacts, including massive loss of jobs and increase in income inequality.

There has been significant debate around the extent to which AI will ultimately impact jobs and economic inequality, with some arguing that AI will be a boon to the job market and others predicting unemployment on scales never seen before. Some governments are starting to take the risk seriously, as shown by the AI Jobs Act, introduced in the US in early 2018. Efforts are also made at more local levels to address potential job loss. For example, the Jobs of the Future Fund, proposed by Jane Kim of the San Francisco Board of Supervisors, is essentially a “robot tax” which would require companies to put money into a fund for every human whose job is displaced by automation.

Longer-term concerns surrounding highly advanced AI have essentially no special-purpose formal structures in place at the government level to manage risk, though recent legislation in the European Union attempts to set a roadmap for developing AI-related policies. It is highly unclear what formal structures at the governmental level would currently be appropriate concerning advanced AI, and for now, investigation and planning for advanced AI risk occurs mainly in the academic, corporate, and non-profit communities.

In the past few years, many non-profits (MIRI, FHI, CSER, FLI, CFI, CHAI, OpenAI)[2] have taken it upon themselves to develop early solutions to help push AI development in safer directions. Groups such as the Partnership on AI, the Institute of Electrical and Electronics Engineers (IEEE), and some groups within governments have also begun trying to understand those risks. These initiatives and structures operate essentially on a voluntary basis. The IEEE "Ethically Aligned AI" program[3] and the Asilomar AI Principles[4] are seen as best practices and general aspirational principles, but they have no specific legal authority or binding force. The nascent Partnership on AI[5] has tenets that are formally binding for members of the partnership, though the enforcement mechanism is unclear and the tenets provide only weak constraints on AI development. Generally, the most effective enforcement mechanism within the AI community today is social stigma, which can harm recruitment and participation for groups and individuals.

In addition to those mentioned above, initiatives by various risk-oriented groups, in particular those mentioned previously, have led to a dramatic increase in AI safety sessions at professional AI conferences and meetings, as well as significantly more research on the technical side. At this point, the most effective short-term strategy for ensuring that AI remains beneficial as it advances may be continued and enhanced support for such AI safety organizations as well as creating government grant funding for AI safety research, to nurture a robust and growing AI safety research community permeating both academia and industry. This could result both in technical solutions being available by the time they are needed, and also in a pool of technically skilled AI safety experts from which governments can recruit expertise when needed.

MYTHS & FACTS ABOUT AI

There are fascinating controversies where the world's leading experts disagree, such as AI's future impact on the job market, if/when human-level AGI will be developed, whether this will lead to an intelligence explosion, and whether this is something we should welcome or fear. To help focus on these real controversies and avoid getting distracted by misunderstandings, the text below clears up some common AI myths.

MYTH: Superintelligence by 2100 is inevitable.
MYTH: Superintelligence by 2100 is impossible.
FACT: It may happen in decades, centuries or never: AI experts disagree & we simply don't know.

MYTH: Only Luddites worry about AI.
FACT: Many top AI researchers are concerned.

MYTHICAL WORRY: AI turning evil.
MYTHICAL WORRY: AI turning conscious.
ACTUAL WORRY: AI turning competent, with goals misaligned with ours.

MYTH: Robots the main concern.
FACT: Misaligned intelligence is the main concern: it needs no body, only an internet connection.

MYTH: AI can't control humans.
FACT: Intelligence enables control: we control tigers by being smarter.

MYTH: Machines can't have goals.
FACT: A heat-seeking missile has a goal.

MYTHICAL WORRY: Superintelligence is just years away.
ACTUAL WORRY: It's at least decades away, but it may take that long to make it safe.

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PROJECTS TO KNOW ABOUT

Over the past decade, various initiatives have been set up to explore potential safety issues associated with the development of artificial intelligence. Seven of those deserve special mention.

- **OpenAI,** a nonprofit research organization developed under the leadership of Elon Musk, aims to discover and enact a path to safe artificial general intelligence, with an aim to make high-powered AI systems available more widely and apart from a corporate profit motive or government structure.
- **DeepMind,** part of the Alphabet Group, has developed several breakthrough AI systems including AlphaGo. It also has a strong safety focus, with an internal ethics board and safety research group.
- **The Machine Intelligence Research Institute (MIRI)** is a non-profit organization originally founded in the year 2000 to research safety issues related to the development of Strong AI. The British non-profits Future of Humanity Institute (FHI), Centre for the Study of Existential Risk (CSER) and Centre for Intelligence have joined this research effort.
- **The Future of Life Institute,** established in 2014 with a mission to support the beneficial use of technology, granted 7 million dollars in 2015 to 37 research teams dedicated to “keeping AI robust and beneficial”.
- **The Partnership on AI,** created in 2016, is a consortium of industry and non-profit members with an aim to establish best practices to maximize AI’s widespread benefit.
- **SAIRC** is a joint Oxford-Cambridge initiative housed by the Future of Humanity Institute, that aims to solve the technical challenge of building AI systems that remain safe even when highly capable, and to better understand and shape the strategic landscape of long-term AI development.
- **AI Now** is “an interdisciplinary research center dedicated to understanding the social implications of artificial intelligence.” They look at issues related to civil liberties, bias, jobs, and safety, especially those that are either currently or soon expected to be impacted by AI.

It’s worth noting that many government groups have been established in the last year or so to observe and join these efforts, including, but not limited to: the European AI Alliance, the European Commission Working Group on the Ethics of AI, the UK Parliament Select Committee on AI, the UK Government’s Centre for Data Ethics and Innovation, and the New York Algorithm Monitoring Task Force.

The AI research and development community has taken an unusually proactive stance toward self-governance, with businesses organizing their own ethics committees and developing incentive systems for research and development, independently of national governments or the UN. While this ensures that the development of norms and guidelines is conducted by people with most expertise in the field, it has also raised concerns as to potential conflicts of interest and balanced representation.

Governance of unknown risks

There is little doubt that global threat paradigms are going to evolve in the coming decades, but can governments prepare for new challenges even before they are identified as such? Many sponsor attempts to do just that. In Singapore, the Center for Strategic Futures has been studying 'wild cards' – improbable futures that would have a massive impact should they become reality. The US marine force has similarly explored surprising futures by asking the marines themselves to write science fiction stories, and the US National Intelligence Council has dealt with potential 'game changers' in a report describing the state of the world in 2030. More recently in 2017, the US Intelligence Advanced Research Activity (IARPA) agency opened the Geopolitical Forecasting Challenge, inviting the public to create new methods that could successfully forecast unexpected geopolitical events, disease outbreaks and other occurrences.

However, these are all projects led by national governments for national interest. The only similar attempts sponsored by multiple governments were two projects erected by the European Union in this last decade – FESTOS and iKnow – inviting global experts to create wild card scenarios about unexpected opportunities and risks. The results, however, have not yet been added to the agendas of other international bodies, or resulted in a coordinated governance body for unknown risks.

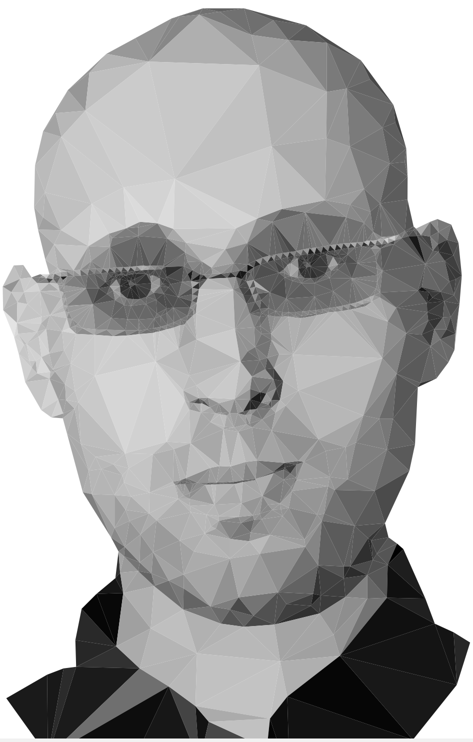
One core insight from those projects has been the role of 'weak signals': hints that a strange future might come closer to fulfillment, and which could be tracked by government analysts. As surveillance technologies leap forward, some nations may be looking for novel ways to gather such weak signals. China, for example, is making use of nearly two hundred million CCTV cameras, together with a facial recognition system, to track citizens and their doings. Predictive policing algorithms are used to forecast the chances of Chinese individuals conducting crime, allowing the police to intervene before the crime is actually carried out. Under the auspices of the Xue Liang ("Sharp Eyes") program, people are supposed to look at recorded clips of others and identify suspicious behavior and possibly weak signals. While this system is mostly expected to lead to "shame and blame", it is conceivable that it will also be used to detect new and unknown risks.

Similar surveillance paradigms that keep an eye for weak signals – within the country or without – might aid in alerting authorities about the near-fruition of wild cards. However, privacy considerations prevent most governments from enacting similar omnipresent surveillance schemes. Furthermore, potential catastrophes are essentially ignored by governments in their strategic plans, under the pressure of limited time, money and attention.

Where governments are lacking, private and public organizations may step in. Some, like TechCast Global, seek expert advice about the likelihood of wild card scenarios becoming a reality, independent of any governmental support. Others, like the Good Judgement Project, invite the wider public – experts and laymen – to assess the chances that both plausible and implausible scenarios will come to fruition within a defined timeframe. By identifying superforecasters – respondents whose forecasts are more accurate than 98% of participants – they can form a more reliable forecast for the short-term future. Another venture, Swarm, utilizes a combination of crowdsourcing and AI, to produce more accurate forecasts than either human beings or predictive algorithms would have come up with on their own. These projects act like electronic prediction markets, where people bet on future events: they outsource signal tracking to a crowd of observers incentivized by market mechanisms to act as monitors.

All of these organizations can serve as a boon to governments. They constantly sniff for subtle hints and weak signals, and are able to alert governments when a related wild card becomes more plausible. Unfortunately, many governing bodies are unaware of these organizations, or even try to confine their activities – as in the case of prediction markets, which are seen as illegal gambling venues and have been terminated in many nations.

The only way to prepare for the unexpected is to construct scenarios ahead of time, and harness collective energies to highlight the more plausible ones as they come closer to fruition. While we cannot be sure what 2020, 2030 or 2050 will look like, if we continue to think about potential wild cards and monitor for weak signals in the present, we will at least be able to reduce the extent of the unknown, and better prepare for new risk scenarios.



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SOLAR GEOENGINEERING

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