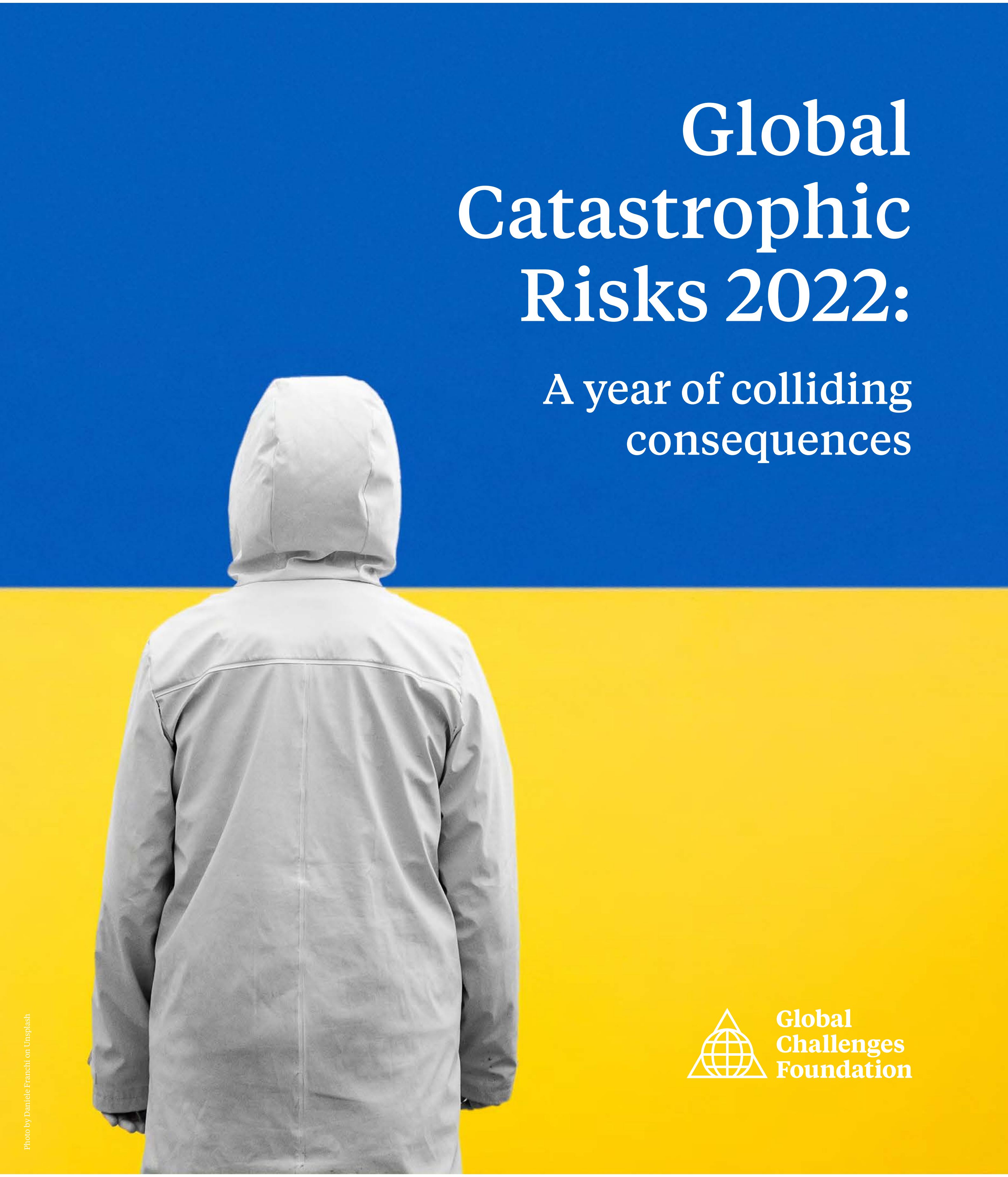

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Global Catastrophic Risks 2022:

A year of colliding consequences

Global Challenges Foundation

GLOBAL CHALLENGES FOUNDATION (GCF) ANNUAL REPORT: GCF & THOUGHT LEADERS SHARING WHAT YOU NEED TO KNOW ABOUT GLOBAL CATASTROPHIC RISKS IN 2022

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Dear reader,

The year 2022 has seen the global threats facing humanity grow and intensify, interlinking and reinforcing one another with far reaching consequences for our future. The current risk landscape illustrates more than ever the need for worldwide collaboration to forge a safer way forward. The insights shared by international experts in this year's Global Catastrophic Risks report from the Global Challenges Foundation provide some knowledge and understanding when dealing with the most serious threats of our time in the most effective and equitable way possible.

Dominating public and political consciousness this year has been Russia's devastating invasion of Ukrain. The loss of life, separation of families and external displacement of over 7.5 million people are hard to comprehend. Moreover, with nuclear-armed Russia on one side, and the United States and NATO countries, also armed with nuclear weapons, on the other, the conflict threatens to upend the fragile nuclear order. In fact, recent changes to doctrines and the development of new nuclear weapons make it more likely than ever that nuclear weapons will be used in either military actions, miscalculation or by accident than at any time since the beginning of the nuclear age.

Moral norms of restraint – primarily deterrence in the form of "mutually assured destruction" – bilateral agreements and international cooperation have so far worked to reduce nuclear arsenals. However, these safeguards are now unravelling at an alarming rate and countries no longer seem to want to cooperate with the Nuclear Non-proliferation Treaty. Without international agreement on the development and use of nuclear arms, the survival of vast swathes of the human population are at risk.

The increasing threat of nuclear attack comes at the same time as emissions around the world continue to rise and the window of opportunity to halt catastrophic climate change narrows. In 2021, despite an unprecedented growth in renewable power generation, global emissions rebounded to their highest level in history.

Globally, the green agenda continues to be shelved and deprioritised in response to other crises, even though global warming is one of the key escalating factors for myriad risks around the world. Most recently, the invasion of Ukraine has caused a ripple effect across Europe and beyond, with energy supplies in jeopardy and food prices soaring. In turn, leaders have moved to shelve green energy initiatives in favour of damage limitation and crisis management. We must find new ways of dealing with multiple risks simultaneously, rather than mitigating one at the cost of escalating another.

▼ Dominating public and political consciousness this year has been Russia's devastating invasion of Ukraine ▼

Due to human action, we are seeing unequivocal warming of the atmosphere, ocean and land. Five of the nine interconnected planetary boundaries that underpin the stability of global ecosystems, allowing human civilisation to thrive, are estimated to have been exceeded, with every region on the planet already affected by more frequent and intense weather extremes. A future governed by catastrophic climate change is starting to feel inevitable without drastic, coordinated, immediate action from the world community.

Both the United Nations General Assembly and the COP27 climate talks have come and gone with little to show in the way of global, collaborative action to reduce, mitigate and prepare for climate-related threats. In fact, worrying dialogues at COP27 saw some leaders place alarming emphasis on using new gas projects to tackle the immediate global energy crisis. However, one success came from the historic 'loss and damage' fund to compensate for climate impact in developing countries. This represents a huge step forward for much needed climate justice.

As climate breakdown accelerates, so too does the risk of future deadly pandemics. Coordinated and extraordinarily rapid development of vaccines, diagnostic tests and medicines have helped control and prevent COVID-19 infection for many in richer countries. Collaboration is the only way we will address future pandemics and global health threats. As the world struggles to recover a sense of normality following the COVID-19 pandemic, a process laced with unacceptable health and vaccine inequality, we are left with the knowledge that this will not be the last pandemic that humanity faces.

Now more than ever we need to recognise that risk does not respect borders – global collaboration to review creative solutions from a multi-national, multi-risk perspective is the only way forward. We need to build new forms of global governance, firmly rooted in equity and rule of law to allow us to tackle multiple global problems. To ensure a habitable, safe and peaceful future, we need to work together.

Yours,

> **Now more than ever we need to recognise that risk does not respect borders**

JENS ORBACK
Executive Director, Global Challenges Foundation

Approach

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 an approach 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 report offers a description of the current risks, exploring what is at stake, what is known, and key factors affecting risk levels. Then, for each risk, the 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 supervolcanic 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 COVID-19, Ebola and Zika outbreaks highlighted the challenges and opportunities of global cooperation.

EMERGING RISKS

Artificial intelligence might not seem like an immediate source of concern. However, we should remember that challenges widely recognised 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.[2]


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Reviewed by
KENNETTE BENEDICT

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]

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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 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 per cent fatalities within a radius of 1 to 4 kilometres from their point of detonation, with very severe damage being felt for up to six times as far[5]. The largest arsenals are currently held by the United States and Russia who control approximately 6,500 warheads each[6]. Seven other states are known to possess nuclear weapons or are widely believed to possess them: the United Kingdom, 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, triggering an inadvertent nuclear war – as has 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 four to five 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.

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WHAT ARE THE KEY FACTORS AFFECTING RISK LEVELS?

Continued efforts towards arsenal reduction will reduce the overall level of nuclear risk. Attention to geopolitical tensions and rising nationalism, along with 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 and the growing threats of cyberattacks on command and control systems. 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 unauthorised 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].

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The dangers of biological and chemical warfare

WHAT IS THE RISK OF BIOLOGICAL WEAPONS?

Unlike nuclear weapons, which require rare materials and complex engineering, biological and chemical weapons can be developed at low cost, placing them within the reach of all states as well as organised non-state actors. Chemical and biological weapons are both outlawed, but due to dual-use materials and their accessibility, they carry various levels of risk.

Technology advances in biology are vital to fighting disease, protecting the environment, and promoting economic development – but these innovations also exacerbate risks of deliberate or accidental misuse, as technological innovation is outpacing national oversight mechanisms. There is no international organisation dedicated to reducing emerging risks associated with advances in technology.

Toxic chemicals could be aerosolised or placed into water supplies, eventually contaminating an entire region. The continuum of biorisks is even higher, ranging from naturally occurring diseases to bioengineered pathogens that could spread worldwide and cause a pandemic.

Recent developments in synthetic biology and genetic engineering are of particular concern. We know that 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 by enhancing the pathogen with "gain of function" by creating a highly lethal and highly infectious agent.

Such pathogens could be released accidentally from a lab, or intentionally released with the intention to cause harm in large population centres. Current trends towards more open knowledge-sharing can both contribute to, and mitigate, such risks. The COVID-19 pandemic – while not an engineered pathogen release – has shown the existential and economic consequences such a pandemic can cause. Concerns over the security of biolabs has increased, as there are no binding international standards for safe, secure, and responsible work on pathogens – and safety lapses and accidents do happen.

Credit/source: Unsplash

What are the key factors affecting risk levels?

- Global frameworks controlling research on chemical and biological weapons, including revised strategic trade controls and potentially sensitive dual-purpose goods, technology and materials; biological and chemical safety and security measures; and an ongoing commitment and capacity to abide by disarmament and arms control conventions.

- The lack of verification in international instruments adds urgency to impartially assessing claims of a hostile outbreak or even the existence of weapon-producing chemical and biological labs, as seen in the allegations by the Russian Federation against Ukraine.

- The unknown number of laboratories researching potential pandemic pathogens for military and civilian purposes, along with the public availability of dangerous information circulating for scientific purposes.

- Further developments in synthetic biology and genetic engineering lowering skill levels and costs to modify existing pathogens or even to develop new pathogens.

- Strengthened biosecurity norms and development of innovative tools to uphold them, working across the public and private sectors to develop practical solutions, including tools and incentive structures to reduce biological risks throughout the research and development life cycle.

- COVID-19 has revealed the lack of meaningful health prevention and preparedness to address biological threats. Only rapid countermeasures will effectively curb any potential outbreak of a pathogen release or even a pandemic to avoid massive harm and economic disruption to populations.

CHEMICAL WEAPONS: IMPUNITY FOR USE?

Inhumane chemical weapons like sulphur mustard gas have instilled horror since their use in World War I and after, resulting the 1993 Chemical Weapons Convention. These are the most-widely used and easily proliferated weapons of mass destruction. While today, 98 per cent of the world population lives under the protection of the Convention, isolated incidents like the 1995 attack in the Tokyo subway against civilians by the domestic terrorist group Aum Shinrikyo are difficult to prevent. Releasing a toxic substance in enclosed or crowded spaces – such as gas, liquid, or solid, in order to cause public panic, injury or loss of life – can be achieved by obtaining common household and professional grade toxic chemicals. These include nerve agents, blister agents, choking agents and irritants if used in excessive quantities.

The last ten years have put the Chemical Weapons Convention under severe strain, as the Syrian war has shown the fragility of upholding the norm against toxic chemical weapons. The international community has established investigative bodies to uncover the facts about chemical weapons use against civilians in Syria, yet attribution is contested and until now, no person or entities have been brought to justice. Isolated attacks against individuals – most recently against Russian opposition figure Alexander Navalny – have occurred, at times with deadly results, yet without accountability. The inability to bring perpetrators to justice could encourage additional actors to acquire a full capability to use chemical weapons.

Another concern is the fact that in conflict, it is often difficult to confirm the veracity of reports of poisonous substances being dropped on armed forces and civilians. Chemical substances can be riot control agents – such as tear gas mixed with chemical agents to cause stronger symptoms and thus incapacitate fighters and civilians – or using chlorine gas which is not prohibited except if used maliciously and with intent to harm. Chemical weapons are weapons of mass destruction, yet they are also weapons spreading mass terror.

In recent years, we have witnessed the difficulty of upholding the common understanding regarding red lines on the use of chemical weapons. The current geopolitical climate has undermined global solidarity on this issue, and a weakening consensus could lead to the devastating use of more advanced chemical weapons in any large-scale conflict. It could also cause long-term changes in how states understand the development, evaluation and use of 'non-standard chemical substances' (other than deadly substances like sarin) for domestic riot control and counter-terrorism operations. This shows that even with very few countries outside the Chemical Weapons Convention, we cannot be confident that chemical weapons are a relic of the past.

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Governance of nuclear warfare

States manage the risks of nuclear weapons through measures that have prevented their worldwide spread but have not significantly reduced the risk of catastrophic use. These measures include mutual deterrence based on the prospect of nuclear retaliation, moral norms of restraint, and international cooperation, most notably the 1970 Nuclear non-proliferation Treaty (NPT). However, recent changes to doctrines and development of new nuclear weapons by the United States, Russia, China and the other nuclear weapons states make it more likely that nuclear weapons will be used in military actions, or through miscalculation or accident, than at any time since the beginning of the nuclear age. Threats by Russia to use nuclear weapons in the current conflict in Ukraine have further heightened the risk of nuclear catastrophe.

The pillar of nuclear military strategy is deterrence, whereby nuclear-armed states threaten massive retaliation against each other in what is termed "mutually assured destruction." This doctrine is considered by some to be an effective way of preventing nuclear war. However, others observe that since no nuclear weapons have been used in any conflict since 1945, political restraint based on a moral norm against their use also may have played a role.

At the same time that major powers relied on deterrence and norms of restraint, bilateral agreements and international cooperation, beginning with the 1963 US-Soviet treaty to ban atmospheric testing, and subsequent US-Soviet/Russia bilateral agreements, have reduced nuclear arsenals from a high of 68,000 in the late 1980s to some 12,000 today. In addition, international cooperation in the form of the 1970 Nuclear Non-proliferation Treaty 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 upon 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). Civilian nongovernmental organizations also play an increasing role in monitoring nuclear weapons developments, using fine-tuned satellite technology. As the use of surveillance technology by independent analysts increases, the ethics of their use may be scrutinized more closely; at present there is no regulation of these practices.

A separate international agreement, the Joint Comprehensive Plan of Action (JCPOA) to prevent Iran's development of nuclear weapons, had been reached in 2015 and served as a means to strengthen Iran's obligations under the NPT. The multilateral arrangement among China, France, Germany, Russia, the United Kingdom, the United States, the European Union, and Iran permitted civilian uranium enrichment by Iran and provided robust oversight of research and production facilities by the IAEA. Unfortunately, however, the United States withdrew from the JCPOA in 2017, and Iran has increased production of enriched uranium beyond that stipulated in the agreement. New administrations in both the United States and Iran currently are engaged in multi-state talks to negotiate a new plan that prevents Iran's enrichment of fuel to weapons grade in exchange for economic sanctions relief, but they have yet to reach a new agreement.

The conflict in Ukraine with nuclear-armed Russia on one side, and the United States and NATO countries, also armed with nuclear weapons, on the other, threatens to upend the fragile nuclear order. For now, all parties are exercising restraint in the face of Russia's aggression against Ukraine. The long-term consequences of this war for the governance of nuclear weapons, and the moral norms that influence state action, however, will be significant if difficult to foresee at this date.

Even before Russia's veiled threat to use nuclear weapons in Ukraine, bilateral and multilateral institutions that restrain nuclear weapons arsenals were unraveling at an alarming rate. Major treaties between Russia and the United States, including, most recently, the 1987 Intermediate Nuclear Forces treaty that had banned an entire class of nuclear-capable missiles in Europe, had collapsed in 2019 with the withdrawal of the United States and then Russia. Only the New START treaty of 2010, renewed through 2025, remains. It limits strategic nuclear weapons of the United States and Russia to 1,550 each and provides for transparent verification measures to ensure compliance. However, no treaty or agreement has sought to limit nonstrategic nuclear weapons, those with yields below 300 kilotons. Russia is suggesting that it might use these tactical weapons in the war in Ukraine should it feel overpowered by conventional forces in a move to "escalate to de-escalate" the conflict. Estimates of Russia's battlefield nuclear weapons range from 1500 to 2000; the United States and NATO deploy an estimated 100 of such smaller nuclear weapons in Europe.

Even with the New START limits on arsenals, however, Russia and the United States have each declared their intentions to use nuclear weapons even if such weapons are not used against them first. Such nuclear postures, as well as Russia's current threats, suggest that nuclear weapons are increasingly viewed as instruments of warfighting rather than solely as deterrents against other states' nuclear threats.

The practice of restraint, once thought to be a result of nuclear deterrence and norms of non-use, as well as formal agreements, is deteriorating.

Evolving doctrines, as well as the development of new, more lethal nuclear weapons suggest that a new arms race is underway. Included in that race are China, which is increasing production of long-range nuclear-capable missiles, North Korea, India, and Pakistan, as well as Russia, the United Kingdom, and the United States. This new nuclear arms race among the nuclear weapon states reinforces the perceived utility of nuclear weapons in warfighting and increases the risk that these weapons will be used.

Arms races also underscore the difficulties of enforcing the Nuclear Non-proliferation Treaty when countries do not wish to cooperate. The original treaty, which is viewed as a major element of global nuclear governance, suggested a bargain whereby those states without nuclear weapons would not acquire them, would have access to civilian nuclear power, and, in exchange, the nuclear weapons states would disarm when conditions warranted. Many believed that the end of the Cold War was such a time, and, while nuclear arsenals have radically decreased in Russia and the United States since 1992, the recent reversal in doctrine and rhetoric suggest that these and other nuclear weapons states have no intention at present of eliminating their nuclear arsenals.

As the nonproliferation regime, informal norms of restraint, and mutual deterrence that regulated nuclear weapons in the past are eroding, new technological developments, when coupled with nuclear weapons, present ever greater danger that they will be used through miscalculation or by accident. Cyber-attacks that may disrupt command and control systems of nuclear weapons; increased reliance on space technology for military purposes; and dependence on artificial intelligence for control of armaments, make states and their weapons systems more vulnerable to adversaries.

Furthermore, no regulatory frameworks are in place to address these new technologies.

In the face of these growing dangers and in reaction to nuclear weapons states' lack of compliance with the disarmament provisions of the NPT, non-nuclear weapons states introduced in 2017 a UN treaty banning all nuclear weapons. One hundred and thirty-five of the 193 member states participated in negotiating the treaty that prohibits developing, manufacturing, possessing, or stockpiling nuclear weapons, as well as threatening their use. While there is no separate verification regime established with this treaty, all signatories must adhere to IAEA safeguards. With 50 ratifications, the treaty entered into force on January 22, 2021. As of May 2022, 86 countries have signed the treaty and 60 have ratified it, adapting their national legislation to comply with its provisions. Not since the Nuclear Non-proliferation Treaty of 1970 have states taken such dramatic and collective action to prohibit possession of nuclear arsenals.

Another bright spot in an otherwise dismal nuclear governance landscape is the Comprehensive Test Ban Treaty and its implementing organization, the Comprehensive Test Ban Treaty Organization (CTBTO). The CTBTO monitors nuclear testing worldwide and publicly holds states accountable for their nuclear programs. It is through this organization that the international community knows of North Korea's nuclear tests and verifies that no other countries have tested nuclear weapons since 1998. While the treaty has not entered into force because key states, including the United States and China, have not ratified it, the CTBTO receives financial and expert support even from those countries, and, along with the TPNW, represents a slim hope for future cooperation to regulate nuclear weapons.

▼ The risk of nuclear weapons use is greater now than at any time since nuclear weapons were first exploded over Hiroshima and Nagasaki ▼

Unfortunately, hostilities between the United States and Russia, until now central leaders in the global nuclear order, have disrupted prospects for governing the numbers and uses of nuclear weapons, and will test state doctrines of nuclear deterrence as well as the capacity of international institutions to restrain nuclear arsenals. The risk of nuclear weapons use is greater now than at any time since nuclear weapons were first exploded over Hiroshima and Nagasaki at the end of World War II.

**The author wishes to thank Laura Rose O'Connor and Shane Warda of International Student Youth Pugwash (ISYP) for assistance in writing this essay.*


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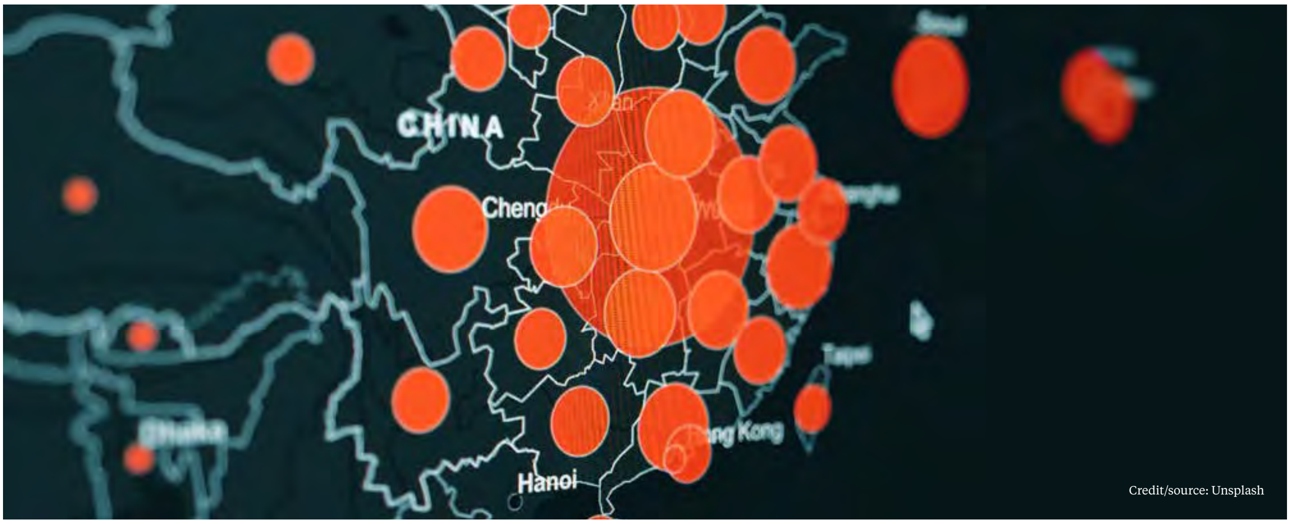
Pandemics: a stark reality

COVID-19 (SARS-COV-2)

The COVID-19 pandemic has brought a genuine global catastrophic risk from merely theoretical and conceptual discussions into stark reality, with far-reaching public policy and global governance implications. Governments are now shifting their strategies to controlling SARS-CoV-2 as an endemic infection, and populations are learning to live with the virus in this third year of the pandemic.

It appears to most public health experts that SARS-CoV-2 is becoming endemic like the four other endemic human coronaviruses. These four endemic coronaviruses, like SARS-CoV-2, have their origin in the animal kingdom and have at some time in the past breached the species barrier and entered human populations. Human beings have learned to live with them as their epidemiology has evolved.

Although SARS-CoV-2 is presently more virulent than the other four human coronaviruses, there is an astounding array of vaccines, diagnostic tests and medicines that will help control and prevent infection. This is thanks to the unprecedented speed with which these tools have been developed, studied, licensed and deployed. However, there are new public policy issues to manage from the success of these tools, notably maintaining vaccine confidence while managing multiple rounds of boosters and maintaining healthy behaviours in populations that may become psychologically reliant on medical interventions.



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On the scientific and virological front, a continuing major concern is whether the tools we have will continue to be effective because SARS-CoV-2, like other RNA viruses, is unstable and will mutate as it replicates in humans. Some mutations of SARS-CoV-2 have been shown to increase its ability to spread from person to person if the opportunity for transmission is created. The question remains as to whether the mutated variants of SARS-CoV-2 will escape the protective effect of the vaccines we have today, whether the many diagnostic tests will continue to identify infection and whether SARS-CoV-2 will become more virulent. In response, scientists continue working on multi-valent COVID-19 vaccines as a step towards the ideal goal of a pan-coronavirus vaccine.

The world has learned much about pandemics during COVID-19. Countries that reacted more rapidly when the World Health Organization provided initial information on 5 January 2020 have been able to maintain low levels of hospital burden and mortality, and many were countries that had previous outbreaks of SARS and MERS coronaviruses that emerged in 2003 and 2012 respectively.

These countries also had strong public health and healthcare systems that permitted them to control outbreaks and accommodate the surge of patients in their health facilities, while ensuring healthcare for others who had non-COVID related illness. The rest of the world has also learned that robust and resilient health facilities are required to respond to the surge of patients caused by a pandemic, and all countries have seen that healthy populations are best able to resist serious illness when infected with newly emerged viruses. We can call this the three inter-locking functions of global health security: strong public health, resilient healthcare and healthy populations.

We have also seen the cost to economies of a pandemic, increased by the response actions by governments that have taken on the function of risk assessment and responded in a manner that required populations to protect themselves and others by being confined to their homes. The challenge now for many governments is to transfer these tasks to the population so that they are able to do their own risk assessment and management – protecting themselves and protecting others as they do for other infectious diseases.

However, early success may not always last; as exemplified by Hong Kong that, at the time of writing, has been unable to fully vaccinate and protect its populations at greatest risk of serious illness after infection. This makes it important that countries build the capabilities to change strategies and policies as the epidemiological situation changes. As the virus evolves, countries must also build systems and infrastructure for the evolution of their scientific, public health and public policy responses.

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WHAT IS AT STAKE?

In the fifth and fourteenth centuries, plague epidemics spread internationally and were thought to have killed approximately 15% of the global population over the course of a few decades. Since then, 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 vaccine development has permitted us to control other infectious diseases such as diphtheria, tetanus, whooping cough and polio; public health and sanitation have reduced the prevalence and impact of yet other infectious diseases such as Typhus and Cholera; and antimicrobial medicines have helped cure or control infections such tuberculosis, AIDS and malaria.

But there is a serious risk that the emergence of yet another new infectious disease in humans will cause a major outbreak or pandemic, with high mortality and rapid spread in our densely populated, urbanised and highly interconnected world. And there is also a major risk that the antibiotics and other antimicrobial drugs on which we depend will become ineffective because of misuse, causing outbreaks of resistant infections that spread first in communities and then within countries and across international borders.

The best means to mitigate such an event is to ensure healthy populations and develop public health and healthcare systems that have the capacity to deal with events such as the COVID-19 pandemic that we are witnessing today. The political will, economic investment and human capital development for these health systems will make the difference between life and death for millions of people, while safeguarding economic growth and national progress.

HOW MUCH DO WE KNOW?

Catastrophic pandemics – diseases with high lethality that spread globally such as COVID-19 – are extremely disruptive, and fortunately have been infrequent in the recent past. Outbreaks of lethal diseases that remain locally contained or pandemics with less acute effects on human health are more common, but they can also have significant disruptive effects.

Outbreaks occur when a micro-organism – virus, bacteria or parasite – 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 other times, 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.

▼The best means to mitigate such an event is to ensure healthy populations and develop public health and healthcare systems▼

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Those micro-organisms that replicate in the respiratory system, especially the passages of the nose, are easiest to transmit from person to person directly and can cause explosive outbreaks. If mutation occurs in a micro-organism as it replicates, or when it combines with genetic material from another micro-organism, virulence can increase or decrease. Mutation can also cause a micro-organism to transmit more or less easily from human to human.

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, and when humans or domesticated animals come into close contact with other animal species that serve as reservoirs for micro-organisms not present in human populations. Experts now consider this is likely to be the way that the HIV/AIDS epidemic started – HIV/AIDS is now endemic in human populations, and its origin is thought to have been a single event when a retrovirus in non-human primates infected a human somewhere on the African continent. Chains of transmission of HIV began from this person, and they were eventually amplified into the HIV/AIDS pandemic when conditions were right.

Infections are easier to contain when they occur among small populations with limited external contact.

Conversely, dense urbanisation and global interconnection strongly increase the risk of an infectious disease spreading internationally.

The broad adoption of hygiene and infection control practices in health facilities can have a significant effect in reducing the local and cross-border spread of an infection. This is especially true in health facilities where infection prevention and control through handwashing and other infection control measures can prevent transmission from amplifying into an outbreak. The capacity to monitor a disease and deploy very rapid containment early in the process can have a large impact on the final number of deaths as well.

Many of the key factors that affect risk levels are scientific in nature, dealing with the epidemiology, statistics, virological and laboratory aspects of pandemics. But there are other key factors that are non-scientific in nature, such as the political will to deliver strong pandemic responses, a resilient public healthcare system that can absorb a surge of healthcare needs, sociological factors of the health literacy and health-seeking behaviours of populations, and even economic factors of investment into health systems and population health.

▼...dense urbanisation and global interconnection strongly increase the risk...▼

RISK SCENARIOS

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 localised 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, despite a relatively small number of cases and deaths. 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 even more serious outcomes. In other words, while health systems can prepare carefully and thoughtfully, the unpredictable elements of luck and timing are also factors that determine the effectiveness of pandemic responses.

▼...the unpredictable elements of luck and timings are also factors that determine the effectiveness of pandemic responses....▼

Credit/source: Unsplash

In late 2013, in the Republic of Guinea in West Africa, an initial infection with the Ebola virus is thought to have occurred, possibly directly from a bat to a Guinean child. Small chains of transmission are thought to have occurred from this infected person, and transmission is thought to have been amplified in healthcare settings where patients admitted without Ebola infection became infected because of weak infection prevention and control measures. Health workers became infected as well, and they served as the entry point of the virus into their families and their communities from where it spread across international borders to neighbouring countries. Over 28,000 persons were reported to have been infected during this outbreak in Guinea, Liberia and Sierra Leone, with over 11,000 deaths.

Infected persons from West Africa travelled to countries in Europe and North America for care, and rigorous infection prevention and control practices in health facilities in these countries prevented spread within health facilities and into communities. It is estimated that in addition to tragic loss of life from Ebola in West Africa, there was a reported increase in death from common infections such as malaria and measles because of the failure of health systems to accommodate needs of those with endemic infections.

These two examples show that there are some similarities in risk scenarios resulting in a global pandemic: animal-to-human transmission, globalized travel causing cross-border infections, and the strength of national-level healthcare systems predicting the quality of pandemic response.

Credit/source: Shutterstock

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; another is the level of immunity in the population; and a third is whether population behaviour creates a risk of transmission.
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.

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 localised.

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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ANTIBIOTICS AND BACTERIA

Antibiotics have saved millions of lives and dramatically increased life spans since they were introduced in the 1940s, allowing us to contain most bacterial infections and diseases. However, more recently, as a result of random mutations due to improper use of antibiotics among humans and animals in agriculture, 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 every year. That number is predicted to reach 10 million by 2050 if efforts are not made to curtail resistance or develop new antibiotics.

There is growing awareness that anti-microbial resistance (AMR) is a species-wide problem. The World Health Organization (WHO) lists AMR as a top ten threat to global health, and there is a growing body of public policy, economic incentives and laws to address AMR.

Two recent examples are the Combating Antibiotic-Resistant Bacteria Biopharmaceutical Accelerator (CARB-X, a global non-profit partnership to find new antibiotics, vaccines and diagnostics) and the PASTEUR Act (a bipartisan bill in the United States that would create advanced market commitments to incentivize pharmaceutical companies to conduct research in anti-microbial agents).

▼Antibiotic-resistant bacteria currently kill an estimated 700,000 people every year▼

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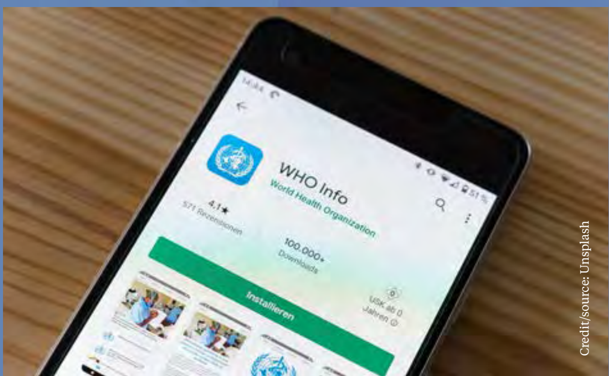
Governance of pandemics

The World Health Organization, established in 1948 as a specialised agency of the United Nations, is currently the global body in charge of governing the risk of and response to 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 to 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.



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Revised in 2005, the IHR now acknowledges 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, SARS in 2003 and COVID-19 in the 2020s. Therefore, emphasis is now placed on the requirement that countries rapidly detect and respond to outbreaks and other public health events with the 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 national public health institutes the role of which is to monitor public health events.

Some of those, including the US CDC, Sante Publique France, and the Nigeria CDC are among the 110 members of the International Association of National Public Health Institutes (IANPHI). IANPHI works to provide mutual support to strengthen capacity to better detect and respond to public health events. When an outbreak occurs, other national institutions, primary health care facilities and hospitals in particular, also 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 the 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.

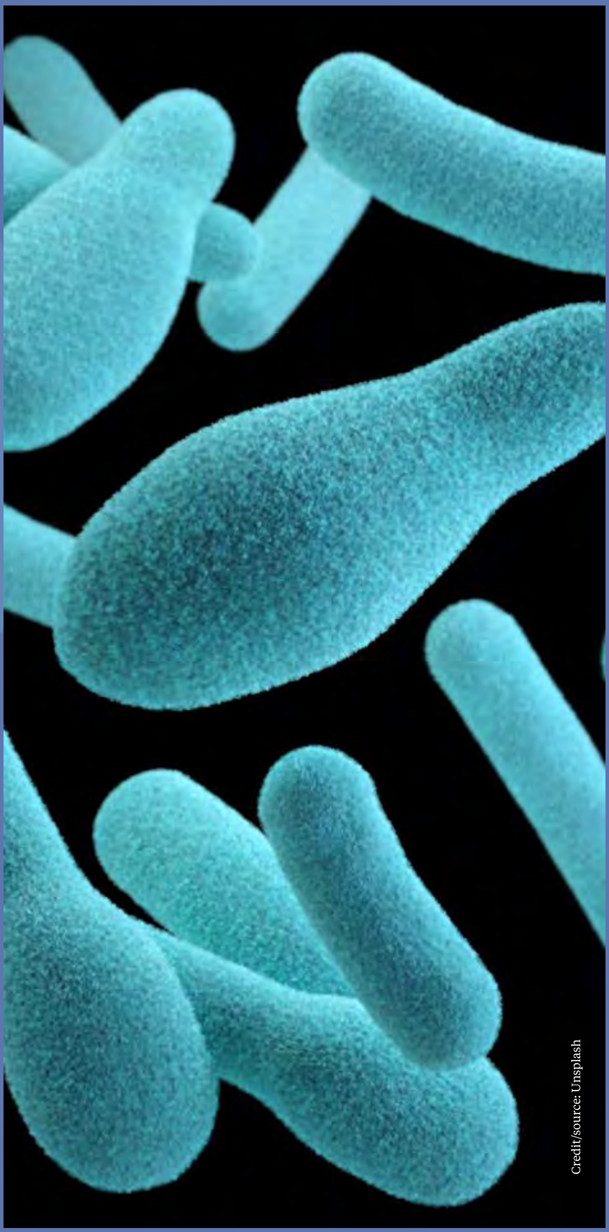
However, there is no sanction for non-reporting, and many countries do not report. As part of the IHR (2005) Monitoring and Evaluation Framework, the Joint External Evaluation (JEE) was developed as a mechanism where a country's core capacity in public health is assessed by a group of international experts. 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 provides 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, the Director General 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 Ebola outbreak in West Africa, an external review of the revised IHR was conducted, and a second review was conducted during the COVID-19 pandemic. Recommendations from that review are now being considered by the World Health Assembly of the WHO.

There are two main improvements needed for the IHR: a stronger enforcement mechanism that utilizes a combination of self-review, peer review and external review; and country capacity-building for low- and middle-income countries. At the same time the WHO is beginning discussions on the possibility of an international treaty to complement the IHR as a result of new understanding gained from the COVID-19 pandemic. These efforts are welcome, especially as COVID-19 will not be the last pandemic that humanity faces.



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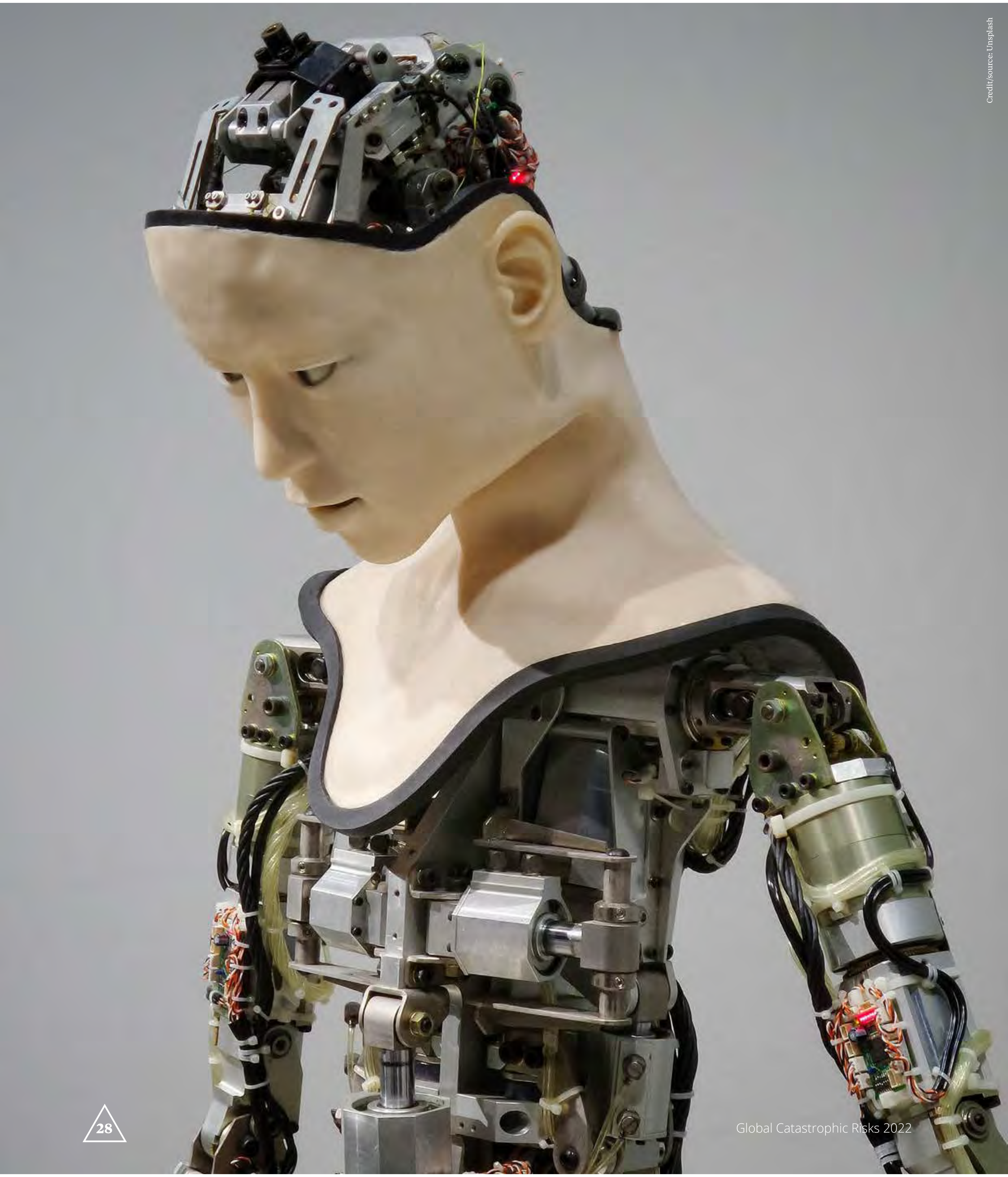

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Artificial Intelligence

Reviewed by
ARIEL CONN

WHAT IS AT STAKE?

Human intelligence has led to the greatest triumphs of humanity, but it is also behind some of history's greatest catastrophes. So what happens if we create artificial intelligence (AI) that's significantly smarter than any person? Will it help us reach even greater heights or will it trigger, as some experts worry, the greatest catastrophe of all: human extinction?

Today's artificial intelligence systems already outperform humans in the tasks they were trained for, especially when it comes to the speed with which they act. In just a matter of seconds, an AI system can play the winning move in chess or Go, translate an article, create an image based on a text description, or plot a route to a given destination while taking into account current traffic patterns.

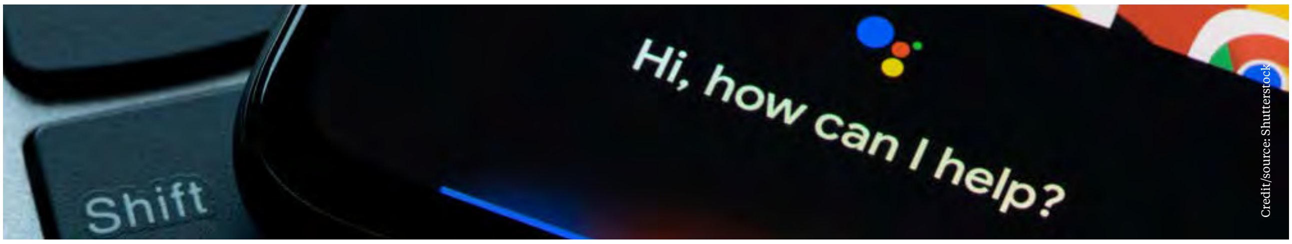
Though a human requires more time to do any of these, a key aspect of human intelligence is that we can perform all of these tasks. We have what's known as general intelligence. While AI systems can only perform the tasks they were trained on, a human can learn from context and experience and develop new skills or solve novel problems.

Many experts worry that if an AI system achieves human-level general intelligence, it will quickly surpass us, just as AI systems have done with their narrow tasks. At that point, we don't know what the AI will do.

ADVANCING AI

Many AI researchers are actively working on developing artificial general intelligence (AGI), most notably, researchers at OpenAI and DeepMind. OpenAI is the creator of GPT-3, which is a powerful text and image generator that's used by over 300 apps, and the organization recently announced the release of DALL-E 2. DALL-E 2 can create impressive images based on text descriptions of just about anything, however, the program has also been plagued by problems of racism and sexism in the images it creates, and OpenAI has implemented safeguards to try to minimize bias and other risks associated with generated content.

In May of 2022, DeepMind announced the release of Gato, a "generalist agent," capable of performing over 600 tasks from playing Atari games to controlling a robot arm and much more. Is this a step closer to achieving AGI? The jury is still out on that one. Researchers at DeepMind suggest it is, however, others point out that the technology that powers Gato is similar to technology that has already existed for many years.



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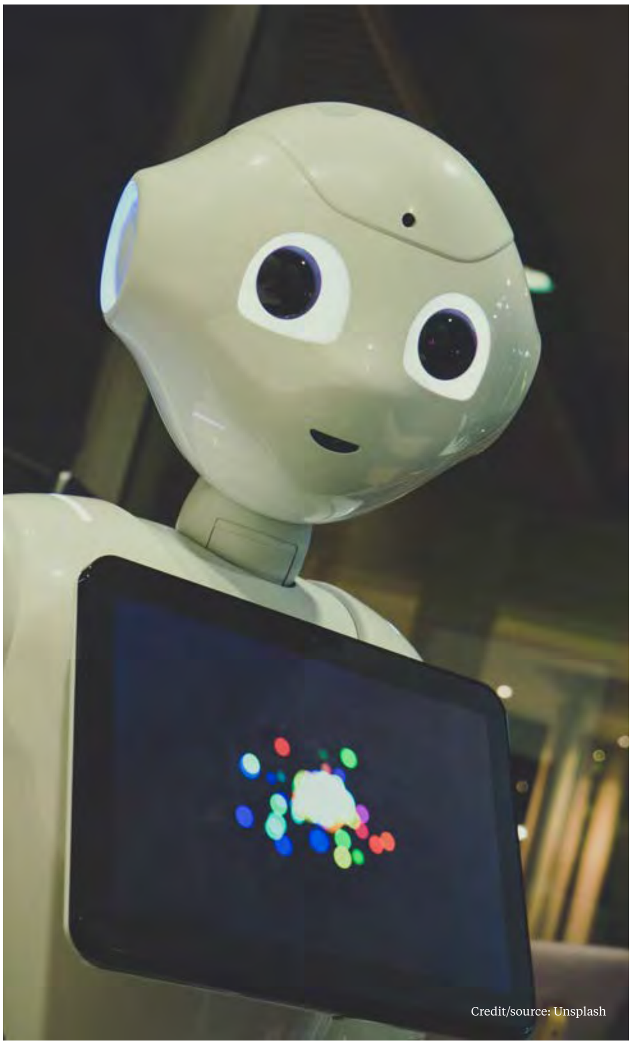
WHY IS THIS A RISK?

First, it's important to note that experts are not worried that an AI will suddenly become psychopathic and begin randomly hurting or killing people. Instead, experts worry that an AI program will either be intentionally misused to cause harm, or it will be far too competent at completing a task that turned out to be poorly defined.

Just looking at some of the problems caused by narrow AI programs today can give us at least some sense of the problems an even more intelligent system could cause. We've already seen that recommendation algorithms on social media can be used to help spread fake news and upend democracy. Yet even as AI researchers race to find ways to prevent the spread of fake news, they worry the problem will soon worsen with the rise of DeepFakes – in which AI programs modify what's seen or heard in a video without the viewer recognizing it's been doctored.

At the same time, AI systems that were deployed with the best of intentions to identify images, parse through job applications, or minimize mindless tasks have inadvertently reinforced institutional racism, put jobs at risk, and exacerbated inequality.

It's not hard to imagine how much worse these problems could get with advanced AI systems functioning across many platforms or falling into the hands of terrorists or despots.



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WHAT DO WE KNOW?

Though science fiction often portrays artificial intelligence systems as humanoid robots, the AI systems we interact with in our daily lives are typically algorithms running in the background of some programme we're using. They work so seamlessly that people outside of the AI world often don't even realize they've just interacted with artificial intelligence.

For now, these programs can only perform those narrow tasks. But it is 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]. The long-term social impact of human-level AI and beyond, however, is unclear, with extreme uncertainty surrounding experts' estimates.

▼...people outside of the AI world often don't even realize they've just interacted with artificial intelligence▼

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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?

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).

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Governance of AI

Governance of AI in the EU

The European Union has taken center stage in efforts to regulate artificial intelligence and its impact on the digital world. The EU is currently in various stages of development of three major Acts that will influence how the world uses AI: The Artificial Intelligence Act, The Digital Services Act and The Digital Markets Act. Though each of these are designed with EU citizens in mind, we can expect each will influence the global use of AI. As was the case with the General Data Protection Regulation (GDPR), the three Acts will require any business and/or website operating in the EU to adhere to the new regulations, even if it's based in another country. Also similar to the GDPR, many analysts predict that these Acts will become gold standards for regulating AI and digitalization. So what does each of these Acts do?

The Artificial Intelligence Act (AI Act)

The EU AI Act is a proposal by the European Commission, which will regulate AI use according to four risk-based categories. The first, "unacceptable risk," includes AI uses that violate fundamental rights. AI systems that fall into this category are prohibited outright and include AI programs that have "significant potential to manipulate persons through subliminal techniques," especially those that target vulnerable groups. Also prohibited would be "AI-based social scoring for general purposes done by public authorities" and law-enforcement use of "'real time' remote biometric identification systems in publicly accessible spaces."

The second category of AI risk is "high risk." Whether or not an AI system is classified as high-risk will depend on the intended purpose of the systems, and whether the system creates "a high risk to the health and safety or fundamental rights of natural persons." The Act provides specific rules to increase transparency, traceability, and robustness for such systems.

The third and fourth categories are "low and minimal risk." These include AI systems such as chatbots (low risk) and spam filters (minimal risk), with regulation of low-risk systems focusing primarily on transparency for the user about their interaction with the system.

Penalties for noncompliance would be fines of up to €30 million (US$31 million) or up to 6% of a company's total annual revenue. While the Act would create the strongest laws to prevent harm from AI, some fear it doesn't go far enough, especially with respect to restricting facial recognition in public, which could be used for mass surveillance.

As of this writing, the European Parliament and EU Member States were in the process of amending the document. A final version of the Act will likely take at least another year or longer to be completed and agreed upon, and after that, companies will have a couple of years to come into compliance.

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The digital services package

In 2020, the European Commission proposed a digital services package which would include The Digital Services Act and The Digital Markets Act. Earlier this year, the European Commission, the European Parliament, and EU Member States announced their agreement on both Acts.

The Digital Services Act (DSA) is a comprehensive regulation that seeks to provide more safeguards for users and consumers of online marketplaces. The DSA requirements will be dependent on the size of the online platforms, with the most stringent regulations being applied to very large online platforms and very large online search engines, defined as having over 45 million users in the EU.

Among the new obligations outlined in the DSA are rules that will

- Require platforms to quickly remove illegal content;
- Provide alternatives to recommendation algorithms based on profiling, and increase transparency around such systems;
- Prohibit "dark pattern," which can manipulate consumers and users into purchases or information sharing;
- Increase protections for minors, such as prohibiting targeted advertising to minors based on their personal data;
- Require regular analysis of algorithms to ensure risk reduction, and much more.

The Digital Markets Act (DMA) is an effort by the EU to make online marketplaces more open to competition. It specifically targets the largest platforms or "gatekeepers," the big tech companies – especially browsers, messengers, and social media – worth billions and with more than 45 million users in the EU each month. One of the primary goals of the DMA is to prevent the largest companies from stifling competition from smaller companies or newcomers to the space. The DMA will also require the "gatekeepers" to enable interoperability, which would, for example, allow users of different messaging platforms to interact with each other.

As with the AI Act, both the DSA and the DMA come with steep fines if companies don't comply. Both digital acts are expected to be finalized within a matter of months (as of this writing), but companies will still have a couple of years to adapt before they'll face penalties.

Governance of AI outside the EU

In the last few years, some of the world's most prominent companies and organizations have developed ethical principles for AI, including groups like Google, SAP, the European Commission's High Level Expert Group on Artificial Intelligence, the Organization for Economic Co-operation and Development (OECD), IEEE's Ethically Aligned Design, the UK House of Lords, the US Department of Defense, UNESCO, NATO, and many more.

However, in all cases, these efforts have been little more than advisory, offering guidelines and suggestions rather than concrete laws and regulations. This situation has proven woefully insufficient as companies like Google, Facebook, and many others have garnered negative public attention for their struggles to address ethics and discrimination, even within their own organizations.

In the US, the White House has called for an AI Bill of Rights, the Algorithmic Accountability Act of 2022 was introduced to Congress in February, and other federal organizations are also looking into a handful of initiatives to address issues of bias and discrimination. These are all in early stages, and it's unclear what impact they'll have or if they'll pass.

Notwithstanding efforts in the EU, which won't go into effect for at least a couple more years, companies continue to be expected to develop AI for good with little real oversight or direction.

Autonomous weapons

Autonomous weapons systems (AWS) are generally considered to be weapons that could select and engage a target, without a person overseeing the decision-making process. AWS have triggered intense ethical and legal debates around the world, as people try to define the extent to which an algorithm can (or should) decide who lives, who dies, and how.

The International Committee of the Red Cross has recommended "that States adopt new legally binding rules," providing three specific suggestions for aspects of autonomy that should be ruled out or regulated. The IEEE Standards Association recently published a document outlining over 60 ethical and technical challenges associated with the development, use and governance of AWS.

However, though member states of the United Nations Convention on Conventional Weapons have considered this question for nearly a decade, they have yet to find consensus on the development and use of such weapons.

Autonomous weapons pose another threat too: if countries race to develop more powerful autonomous weapons, they could inadvertently find themselves in a race for advanced AI more generally. In such a situation, developers may cut corners or get sloppy in their efforts to be the first to create something new, and the resulting artificial intelligence systems are more likely to behave unpredictably or cause problems in some way.

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Near-Earth asteroids

WHAT IS AT STAKE?

The largest near-Earth asteroids (> 1 km diameter) have the potential to cause geologic and climate effects on a global scale, disrupting human civilization, and perhaps even resulting in extinction of the species. Smaller NEOs in the 140 meter to 1 km size range could cause regional up to continental devastation, potentially killing hundreds of millions. Impactors in the 50 to 140-meter diameter range are a local threat if they hit in a populated region and have the potential to destroy city-sized areas. NEOs in the 20 to 50 meter diameter range are generally disintegrated in Earth's atmosphere but even an airburst can cause localized blast and impact effects.

▼...disrupting human civilisation and perhaps even resulting in extinction of the species ▼

HOW MUCH DO WE KNOW?

Surveys of the NEO population on-going since the 1990s have discovered almost 29,000 NEOs of all sizes as of May 2022. A new record 3087 NEOs of all sizes were discovered in 2021. It is believed that the current surveys have discovered more than 96% of the population of NEOs larger than 1 km in diameter – 878 individual asteroids. In the United States, NASA's Planetary Defense Program has a Congressionally directed objective to discover at least 90% of potentially hazardous asteroids 140 meters and larger in size. As of 19 May 2022, 10,081 NEOs larger than 140 meters have been discovered. This is estimated to be approximately 40% of the total population of NEOs this size or larger.

Smaller asteroids are also continually being discovered, with the reservoir of NEOs with diameters between 50 and 140 meters expected to be approximately 300,000, making these the more likely impact threat in the near term. Impactors of these sizes are expected to have an average frequency of one per ~1000 years. The Tunguska event (1908) is believed to have been an impactor in the lower end of this size range. The total number of NEOs larger than 10 meters could be as high as 50-100 Million.

WHAT ARE KEY FACTORS AFFECTING RISK LEVELS?

The assessment of the risk presented by a NEO is related to the probability of impact with Earth, the size and composition of the asteroid, and where on Earth the impact occurs. Beyond discovery of NEOs, the risk assessment for a NEO with the potential to impact Earth requires an observational assessment programme to refine knowledge of the orbit and to characterize the size and composition of the asteroid. This could include specialized ground and space based observations, or a spacecraft reconnaissance mission to the asteroid. Accurate orbital knowledge is required to establish the "impact corridor" – the areas on Earth where, given uncertainties in the orbital knowledge, the impact is most likely to occur. The impact location and potential severity of damage will determine the risk level, and the required governmental response, either in terms of disaster preparedness or potential asteroid deflection attempts.

The recent sample return missions to the asteroids Ryugu (Hayabusa2) and Bennu (OSIRES-REx) contribute considerably to our knowledge of these NEOs. Hayabusa2 returned in December 2020 5.44 g from Ryugu to Earth. The main objectives of these missions were scientific, but the characterisation of natural parameters of these objects is also important for planning of potential future Planetary Defence missions.

On 11 March 2022 the small asteroid 2022 EB5 impacted Earth over the North Atlantic Ocean. This object, which is only 1-3 meter in size, was discovered in space a few hours before impact. It was the 5th object that has been discovered in space by the surveys before an actual impact.

In the event of a credible impact threat prediction, warnings will be issued by the IAWN if the object is assessed to be larger than 10 meters in size. If the object is larger than about 50 meters and the impact probability is larger than 1% within the next 50 years, the SMPAG would start to assess in-space mitigation options and implementation plans for consideration by the Member States. With vigilance and sufficient warning, an asteroid impact is a devastating natural disaster that can be prevented.

▼ With vigilance and sufficient warning, an asteroid impact is a devastating natural disaster that can be prevented ▼


Credit/source: Unsplash

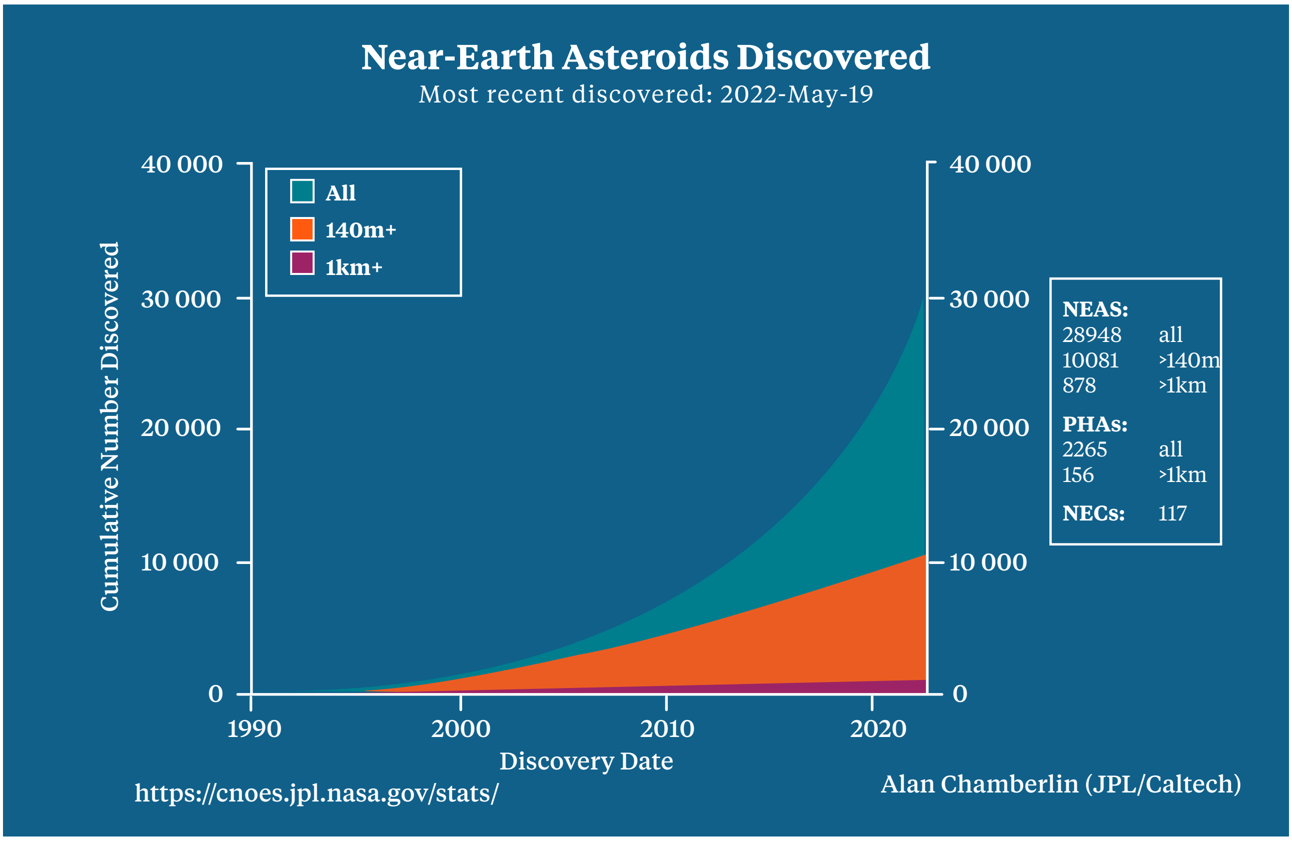
LAUNCH OF THE FIRST-EVER PLANETARY DEFENCE TECHNOLOGY DEMONSTRATION MISSION

The year 2021 witnessed the launch of the first ever planetary defence technology demonstration mission, the Double Asteroid Redirection Test (DART) by NASA in November 2021, which will demonstrate the kinetic impact deflection technique. DART will impact Dimorphos, the small 160-meter companion of the 780-meter large Didymos, in late September 2022.

It will test the capabilities to deflect an asteroid by a high velocity impact of the spacecraft. A few years later ESA will launch the HERA spacecraft to study the impact effects in detail. If successful, these missions will demonstrate that an impact can be avoided by active measures if the object is discovered several years in advance of the potential impact.

SMPAG has started to perform exercises to test its capabilities and coordination in case of realistic impact threats.

These hypothetical exercises are aimed at clarifying the working procedure, form of recommendations and flow of information among SMPAG members with the main goal to define appropriate advice on planetary defence measures, like civil protection or asteroid deflection for decision-makers. The hypothetical exercises will also help identify missing technologies and other potential deficiencies in the field of space-based NEO mitigation.



Governance of near-Earth asteroids

The issue of near-Earth objects (NEOs) has long been on the agenda of the Committee on the Peaceful Uses of Outer Space (COPUOS), the primary United Nations body for coordinating and facilitating international cooperation in space activities, established in 1959 by the UN General Assembly and supported by the Office for Outer Space Affairs (UNOOSA). In the last year several important events have contributed to our understanding of NEOs and to a better preparedness in case of a real impact threat.

The International Asteroid Warning Network (IAWN) and the Space Mission Planning Advisory Group (SMPAG) provide mechanisms at the global level to address the global challenge posed by NEOs, including detection, tracking and impact risk assessment and, subsequently, planetary defence measures like civil protection or asteroid deflection.

UNOOSA, through the IAWN and SMPAG, facilitates the dissemination of information related to NEOs to UN Member States. Important linkages are being made with civil protection communities, including through UNOOSA's UN-SPIDER programme and its global network of Regional Support Offices (RSOs).

Coordinating action in planetary defence

The IAWN links together the institutions that are already performing many of the proposed functions, including: discovering, monitoring and physically characterizing the potentially hazardous NEO population. One of its purposes is to maintain an internationally recognized clearing house for the receipt, acknowledgment, and processing of all NEO observations. The International Astronomical Union sanctioned Minor Planet Center hosted by the Smithsonian Astrophysical Observatory serves this purpose. IAWN recommends policies regarding criteria and thresholds for notification of an emerging impact threat.

IAWN also assists Governments in the analysis of impact consequences and in the planning for mitigation responses, using well-defined communication plans and protocols (see iawn.net). As of June 2022, there are 38 official signatories to the IAWN Statement of Intent.

The SMPAG, (pronounced "same page") is composed of Member States with space agencies or inter-governmental entities that coordinate and fund space activities and are capable of contributing to or carrying out a space-based NEO mitigation campaign. In the event of a credible impact warning by the IAWN, the SMPAG would assess and propose through their member Governments space-based mitigation options and implementation plans for consideration by the Member States.

SMPAG currently has 18 members and 7 permanent observers, with UNOOSA acting as its secretariat. In 2016, SMPAG established the Ad-Hoc Working Group on Legal Issues to address possible legal questions related to the work of SMPAG. This group published a report entitled ´Planetary Defence Legal Overview and Assessment´ (see smpag.net under ´Documents and presentations´).

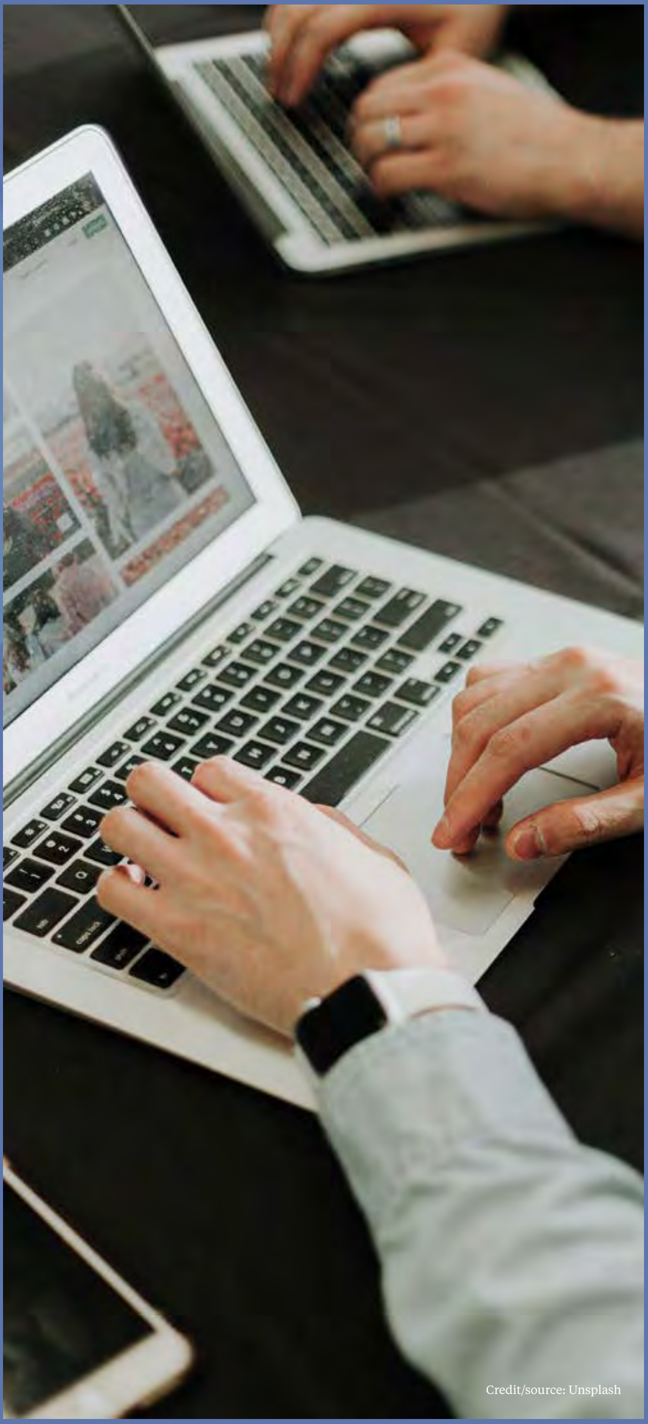
International Asteroid Day

As part of the effort to raise awareness about this topic, the UN General Assembly proclaimed in resolution A/71/492 that International Asteroid Day would be observed annually on 30 June to raise public awareness of the asteroid impact hazard. 30 June is the anniversary of the Tunguska impact over Siberia in what is now the Russian Federation, which occurred on 30 June 1908. That event was Earth's largest confirmed asteroid impact in recorded history, devastating over 2,000 square kilometres of forest.

Biannual Planetary Defense Conferences (PDC)

As the key biannual global conference that brings together key experts in this area, the 7th International IAA (International Academy of Astronautics) PDC was hosted by UNOOSA from 26 to 30 April 2021 as a virtual conference that attracted a wide audience, with more than 700 participants from all over the globe. Highlight presentations included results from the sample return space missions Hayabusa2 (led by JAXA) and OSIRIS-REx (led by NASA), and latest status information on the upcoming missions DART and HERA which will demonstrate the capability to deflect an asteroid by the kinetic impactor technique. The 2021 PDC also included a number of dedicated panels on different aspects of Planetary Defence. In a panel with Heads and Representatives of Space Agencies, 11 high ranked officials (from AEB, AEM, Austrian Space Agency FFG, CNSA, ESA, KASI, NASA) gave statements and expressed their support for international collaboration on Planetary Defence issues. Presentations and recordings of the 7th IAA PDC 2021 are available at here.

The 8th PDC will be held 3-7 April 2023 in the Vienna International Centre, Vienna, Austria and hosted by UNOOSA in cooperation with the European Space Agency (ESA), as an in-person and hybrid meeting.



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Climate catastrophe

Reviewed by
JOANA CASTRO PEREIRA

WHAT IS AT STAKE?

Catastrophic climate change has been associated with an increase in global average temperature of >3°C[1]. This level of global warming would probably imply a serious shift in global climate patterns, unprecedented loss of landmass creating large flows of climate refugees, significant risks to regional and global food security, a combination of high temperature and humidity jeopardising normal human activities, and massive species extinctions having adverse cascading effects on ecosystem functioning and services critical for sustaining humanity[2].

Catastrophic climate change would be triggered by crossing one or more tipping points of the Earth's climate system. Decision-makers have tended to assume that tipping points are of low probability and poorly understood, in spite of growing evidence that these tipping points may be more likely than previously thought, have high impacts and interact in complex and dangerous ways, threatening long-term irreversible changes[3]. Political discussions about climate change rarely acknowledge catastrophic climate risk[4].

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. At the dawn of the Industrial Revolution, the global average atmospheric carbon dioxide was approximately 280 ppm; in 2020, it reached almost 413 ppm – a new record high amount. Current carbon dioxide levels are the highest in at least 800,000 years[5].

According to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC), human influence has unequivocally warmed the atmosphere, ocean and land. The climate system is undergoing unprecedented changes in human history. Every region on the planet is already being affected by more frequent and intense weather and climate extremes. Much of the damage caused by climate change (e.g., changes in the ocean, ice sheets and global sea level) is now irreversible[6]. The global average mean surface temperature for the period 2017 to 2021 is among the warmest on record (1.06°C to 1.26°C above pre-industrial levels)[7].

▼...adverse cascading effects on ecosystem functioning and services critical for sustaining humanity▼

There is an estimated 50% chance that global temperature will temporarily reach the 1.5°C threshold – the aspirational temperature goal of the Paris Agreement – in the next five years[8]. Current policies and climate targets are expected to lead to a global warming increase of approximately 2.7°C and 2.4°C, respectively, by the end of the century[9].

Climate change is a non-linear phenomenon where tipping points play a determining role[10]. When warming rises above a certain level, self-reinforcing feedback loops set in, and the concentration of greenhouse gases increases rapidly. Although precise thresholds and exact scenarios remain very uncertain, we know that the level of risk increases with the rise in temperature. The latest science suggests that tipping points could be exceeded even between 1.5°C and 2°C[11]. For example, at 2°C of warming there is a 10-35% chance that the Arctic becomes largely ice-free in summer[12].

Scientists recently found that 45% of all potential ecological collapses are interrelated and could reinforce one another[13]; in other words, 'exceeding tipping points in one system can increase the risk of crossing them in others'[14].

Limiting the Earth's temperature rise to 1.5°C is thus not only crucial for saving the majority of the world's plant and animal species[15] as well as safeguarding low-lying island states from sea level rise and the poorest countries from climate extremes[16], but also a precautionary step to prevent triggering climate tipping points.

In its 2018 special report, the IPCC estimated that the remaining carbon budget to stand a reasonable chance (66%) of limiting warming to 1.5°C would be depleted by around 2030[17]. The panel's conclusions were, however, criticized for being too conservative[18].

▼...at 2°C of warming there is a 10-35% chance that the Arctic becomes largely ice-free in summer▼

Considering, for example, an upper estimate of a wide range of potential Earth system feedbacks, humanity might have already exceeded the remaining budget to limit warming to 1.5°C (66% probability)[19]. Moreover, mitigation pathways compatible with 1.5°C imply the deployment of negative emissions technologies (e.g., bioenergy production with carbon capture and storage)[20], and advances on these by science and policy are currently far from ideal[21].

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CLIMATE TIPPING POINTS

The Earth's climate system is formed by large-scale components characterized by a threshold behaviour known as tipping elements. Put another way, climate tipping elements are supra-regional constituents of the Earth's climate system that may pass a tipping point[22]. The Greenland ice sheet and the Amazon rainforest are examples of tipping elements. A tipping point is 'a threshold at which small quantitative changes in the system trigger a non-linear change process that is driven by system-internal feedback mechanisms and inevitably leads to a qualitative different state of the system, which is often irreversible'[23].

WHAT ARE KEY FACTORS AFFECTING RISK LEVELS?

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

First, 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[24]. As to methane emissions, they largely relate to large-scale animal farming, driven by demand for meat, dairy and wool[25].

Second, some ecosystems store large amounts of carbon, particularly forests and coastal marine ecosystems, and their destruction could result in the large-scale release of greenhouse gases into the atmosphere[26].

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[27].

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 radiation management techniques (namely, stratospheric aerosol injection) to reduce the risk of catastrophic climate change, which might harm in other ways[28] – and ensure human development and the protection of the non-human living beings that enable life on the planet to thrive.

▼The Greenland ice sheet and the Amazon rainforest are examples of tipping elements▼


Photo/source: Unsplash

CO2 EMISSIONS ON THE RISE

According to a 2021 report by the International Energy Agency[29], in 2020 primary energy demand dropped by approximately 4% and global energy-related CO2 emissions fell by 5.8%. The unprecedented reduction in oil demand during 2020 (8.6%) – mostly associated with the drop in road transport and aviation activity – accounted for over half of the reduction in global emissions. In turn, low-carbon fuels and technologies accelerated their expansion; rising from 27% in 2019 to 29% in 2020, the share of renewables in the global energy mix reached the highest annual increase ever recorded. The COVID-19 pandemic resulted in a decline in emissions of nearly 2,000 million tonnes of CO2 – in absolute terms, the largest-ever decline in global emissions[30].

However, as the pandemic is brought under control and the global economy stirs to life, emissions are on the rise again. In 2021, and despite an unprecedented growth in renewable power generation, global emissions rebounded to their highest level in history. The recovery of energy demand was compounded by the rise in natural gas prices, which resulted in more coal being burned. It is clear that the world is not growing back greener[31]. Although green spending is rising, it is not enough for a sustainable recovery.

According to the Organisation for Economic Co-operation and Development (OECD), the budget allocated to environmentally positive measures has recently reached USD 1090 billion. Yet 'potentially environmentally harmful government support amounts to more than USD 680 billion annually around the world, including subsidies to fossil fuel production and consumption, and environmentally harmful agricultural support', meaning that 'after only two years, these subsidies already cancel out the USD 1090 billion of green spending to be spent over multiple years'[32].

▼In 2021... global emissions rebounded to their highest level in history▼

CLIMATE CHANGE, BIODIVERSITY LOSS AND HUMAN HEALTH

The COVID-19 global health crisis urges us to rethink our relationship to nature and the non-human species with which we share the planet.

The coronavirus has been attributed to anthropogenic interferences on the natural world such as deforestation, which is a major contributor to climate change; encroachment on animal habitats; and biodiversity loss, which is driven, among other factors, by climate change[33]. The crisis is a reminder of our enmeshment in a more-than-human world[34]. It also calls our attention to the critical links between climate change and biodiversity loss, and their impacts on human health.

By eroding wild spaces, largely for agriculture and mostly for raising cattle or growing crops to feed them, changing the climate – thus forcing animals to find food and shelter close to people or migrate to the poles to escape heat, which creates new opportunities for pathogens to get into new hosts – and by trading and consuming wild animals, we increase the likelihood that zoonotic viruses will jump to humans. Moreover, we know that global warming makes conditions more favourable to the spread of some infectious diseases, while air pollution makes people more vulnerable to infection[35].

We also know that when biodiversity declines, the species that thrive are the ones that are best at transmitting diseases (e.g., bats and rats)[36]; as current species extinction rates have no parallel in human history[37], there are strong reasons for concern.

A recent study suggested that species migrating due to climate change are potentially already propagating their viruses further. It also concluded that climate change might become the main anthropogenic driver of virus transmission across species by 2070, and that 'holding warming under 2 °C within the century will not reduce future viral sharing'[38]. The most affected areas are predicted to be biodiversity hotspots and densely populated areas in Asia and Africa[39].

Current and future policies must thus integrate climate, biodiversity and health considerations as well as the needs and rights of the non-human living beings with which we share the Earth.

▼...climate change might become the main anthropogenic driver of virus transmission across species by 2070▼

Governance of climate catastrophe

The challenge of climate change has been defined as a 'super-wicked' problem. It is intricately linked to everything else – energy, land use, food, water, transportation, trade, development, housing, investment, security, etc.[1]. Solving it requires tremendous, unprecedented collective action by countries with very heterogeneous interests, priorities and circumstances[2], where powerful forces pushing for environmentally destructive development have prevailed thus far[3]. The sharing of responsibility in mitigating climate change has thus been a central challenge in international negotiations[4].

The Paris Climate Agreement, signed in 2015 and in force since November 2016, avoids the critical issues of the allocation of responsibilities for safeguarding the climate and fairness of each country's mitigation efforts[5]. In addition, it fails to include legal obligations determining concrete mitigation actions; means for coordinating the countries' contributions[6]; solid mechanisms for monitoring the implementation of national pledges; and tools to punish the parties that do not comply with its provisions[7]. Moreover, the rules established for operationalizing the agreement provide very few obligations for countries to implement ambitious climate action at the domestic level[8].

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The 26th Conference of the Parties (COP) to the United Nations Framework Convention on Climate Change (UNFCCC), which took place in Glasgow in 2021, was expected to deliver on a number of critical outcomes, namely limiting global temperature rise, mobilising increased climate finance and establishing rules for a credible global carbon market. While progress was made in several areas, the world is still far from the action needed to safeguard the Earth's climate. The meeting was unable to put the world on track for the 1.5°C temperature global. The Glasgow decision thus urges parties to the Convention to revisit and strengthen their 2030 targets by the end of this year, so that they match the temperature goals of the Paris Agreement. It also calls on those that have not yet submitted a long-term strategy for 2050 to do so.

Financing pledges by rich nations also fell short. In 2009, developed countries had committed to mobilize USD 100 billion a year by 2020 to assist the mitigation efforts of developing countries; yet, at COP26, they declared that they would not meet that goal until 2023. A process to develop a new, larger finance target to take effect after 2025 was agreed.

Following COP27, commentators noted that commitments regarding limiting temperatures to 1.5 degrees celsius have not progressed since COP26 and that the language about the need to phase out fossil fuels is weak. However, one success came from the historic 'loss and damage' fund to compensate for climate impact in poorer, low-emission nations.

Regarding carbon markets, parties came to an agreement on the need to avoid double-counting (that is, a situation in which both the country selling and buying carbon credits claim the same carbon emission reduction or removal).

However, they also agreed to allow the carry-over of emissions reductions from the Kyoto Protocol to help them comply with commitments made under the Paris Agreement which, in the absence of stringent rules to ensure that older credits represent real emissions, might compromise the integrity of carbon markets. On a more positive note, there was, for the first time, an unequivocal call to phase down coal and fossil fuel subsidies[9].

Outside formal negotiations, countries made collective commitments to halt and reverse forest loss; curb methane emissions; phase out domestic coal; end new licensing rounds for hydrocarbon exploration and production; redirect investments in unabated fossil fuels towards clean energy; put financial institutions on track to help transform the economy to net zero; create early markets for emerging green technologies, among others[10]. It is critical, nevertheless, to move from rhetorical commitments to concrete action on the ground. The failed history of three decades of international efforts to prevent dangerous anthropogenic interference with the climate system raises significant doubts on the capacity of states to deliver on their promises.

It appears unlikely that the international community will be able to prevent global warming from exceeding 1.5°C. In this context, we need to prepare for dealing with the consequences of an increasingly unstable ecological environment and mitigating the risk of a climate catastrophe. There are, however, a number of limitations and obstacles that challenge our ability to do so[11]. The next paragraphs highlight some of them.

The first is the fact that our brain is wired to process linear correlations, not sudden, rapid and exponential changes; our cognitive expectations are failed by the uncertainty and non-linearity of socio-ecological systems[12].

In addition, our political-legal system was developed to address structured, short-term, direct cause and effect issues (the exact opposite of the climate issue); our institutions provide simple solutions with immediate effects[13]. Moreover, managing catastrophic risks requires proactivity to anticipate emerging threats, mobilize support for action against possible future harm and provide responses that are sufficiently correct the first time, as those risks offer little or no opportunity for learning from experience and revising policies. Nevertheless, in addition to the fact that few existing institutions are capable of acting in this manner, there is the risk that such a proactive approach translates into oppressive behaviours and security measures[14].

The second is the possibility of creating a new risk through efforts to prevent another[15] (e.g., large-scale deployment of bioenergy with carbon capture and storage to help preventing catastrophic climate change, which would erode natural habitats and cause the loss of biodiversity, thus increasing the risk of ecological collapse).

Third, mitigating the risk of a climate catastrophe requires that current generations resist short-term individual benefits with the aim of improving the far future of human civilization. Many people lack motivation to help the far future[16].

Fourth, there tends to be a general distrust in human agency in the face of high-magnitude situations that demobilizes people. In addition, people tend to experience strong, mobilizing feelings about recent, visible events, and develop feelings of compassion especially when a subject is given a face – as societies are only begining to experience global climate catastrophe and nature is a vast and blurred subject, public and political concern for that possibility remains low[17].

Finally, averting a global climate catastrophe requires deep levels of global cooperation. Global cooperation is, nevertheless, currently facing enormous challenges. Although there is a chance that the war in Ukraine will prompt a long-term shift towards sustainability as a strategy to free Western countries from their energy dependence on Russia[18], the tense international environment triggered by the conflict might complicate climate negotiations.

More research is needed to increase our understanding of catastrophic climate risk, better reach the public and pressure political actors to act.

▼...people tend to experience strong, mobilizing feelings about recent, visible events, and develop feelings of compassion especially when a subject is given a face...▼

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Reviewed by
STEPHEN SPARKS

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. 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. Some have argued that Toba caused the greatest mass extinction in human history, bringing our species to the brink of extinction.

Supervolcanic eruptions are events in which at least 400 km^3 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. Existing data suggest that a supervolcanic eruption will occur every 17,000 years on average – with the last known event occurring 26,500 years ago in New Zealand. 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, which have been identified as potential sites of a future supervolcanic eruption.

We are currently unable to anticipate volcanic eruptions beyond a few weeks or months in advance...

Credit/source: unsplash

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 and severe environmental effects.

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.

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.

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.

At the top of the scale, supervolcanic eruptions magnitude 8 and above release more than 400 km^3 of magma.

By comparison, the largest volcano eruption recorded in human history, the 1815 Tambora eruption in Indonesia, was a magnitude of about 7: 41km^3 of magma was expelled, claiming over 70,000 lives. When Mount Vesuvius erupted in 79 AD, devastating the Roman cities of Pompeii and Herculaneum, it released approximately 4km^3 of magma, placing it at magnitude 6. More recently, the May 1980 eruption of Mount St. Helens in Washington, USA, with just over 0.5km^3 released, was a magnitude 5.1.

Credit/source: Unsplash

The largest recorded volcanic eruptions

VEI = Volcanic Explosivity Index

Governance of global catastrophic volcanic eruption

Monitoring volcanoes is largely the 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 1,000, consisting both of academics and Volcano Observatory staff. IAVCEI coordinates 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.

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Reviewed by
PHILIP OSANO

Ecological collapse

WHAT IS AT STAKE?

Since the mid-1950s, many elements that ensure the habitability of the planet, including greenhouse gas concentration, forested areas or the health of marine ecosystems, have been declining at an accelerating pace[1], negatively affecting ecosystems which are the foundation for human life. Ecosystems perform a range of functions, referred to as environmental services, without which human societies and economies would not operate at their current level[2]. We depend on environmental services for air, water, food and fiber, shelter and energy. Ecosystems can tolerate a measure of impact from human use and recover after a period of time with minimal negative effects – an attribute generally known as resilience – but beyond a certain threshold, or "tipping point", sudden and radical disruption can occur, which may lead to "ecosystem collapse"[3]. Under such conditions, soil quality, freshwater supplies and biodiversity diminish drastically, while agricultural capacity plummets and daily human living conditions deteriorate significantly[4].

Although little studied, new evidence is emerging on "ecosystem collapse" due to among other factors, including human pressure and climate impact[5]. Several historical and current examples of " ecological collapse" have been recorded. The former includes Easter Island[6], and the latter include the ecological collapse in and around the Aral Sea which led to dramatic social and economic consequences[7] before gradual recovery[8].

Another example is the ecological changes witnessed in and around Lake Chad that have affected human livelihoods with dramatic negative impacts on people and ecosystem of the region; the diminishing water resources and the decline in the lake's ecosystem has led to severe health and economic impacts for the populations around Lake Chad, and has affected fishing communities and pastoralists, and generated resource-based conflicts[9].

In today's globalized and tightly 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[10]. And with no time for effective recovery – and amplified by climate change impacts[11] – drastically compromise the planet's capacity to sustainably support a large and growing human population.

Credit/source: Unsplash

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[12].

Scholars describe the current historical moment as the start of a new geological era, called the Anthropocene, where humans as the predominant agent of change at the planetary level change the nature of nature itself[17]. 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. Recent assessment shows that humanity has exceeded the safe limits for five of the planetary boundaries and are now operating in a high-risk zone for biosphere integrity and biogeochemical flows[18]. New evidence suggests that changing course to stop the pervasive human-driven decline of life on Earth requires transformative and immediate change[19].

Human-induced factors that affect ecosystem stability and contribute to biodiversity loss may be classified into the following categories:

- Changes in the balance of local biodiversity caused by human activities, for example, the introduction of ‘invasive' species or overharvesting of plants and animals[13]
- Alteration of the chemical balance in the environment – soil, water and air – due to pollution[14]
- Modifications in the local temperatures and water cycle because of climate change[15]
- Habitat loss, whether through destruction or ecosystem fragmentation in terrestrial and water/sea systems[16].

Credit/source: Unsplash

WHAT ARE KEY FACTORS AFFECTING RISK LEVELS?

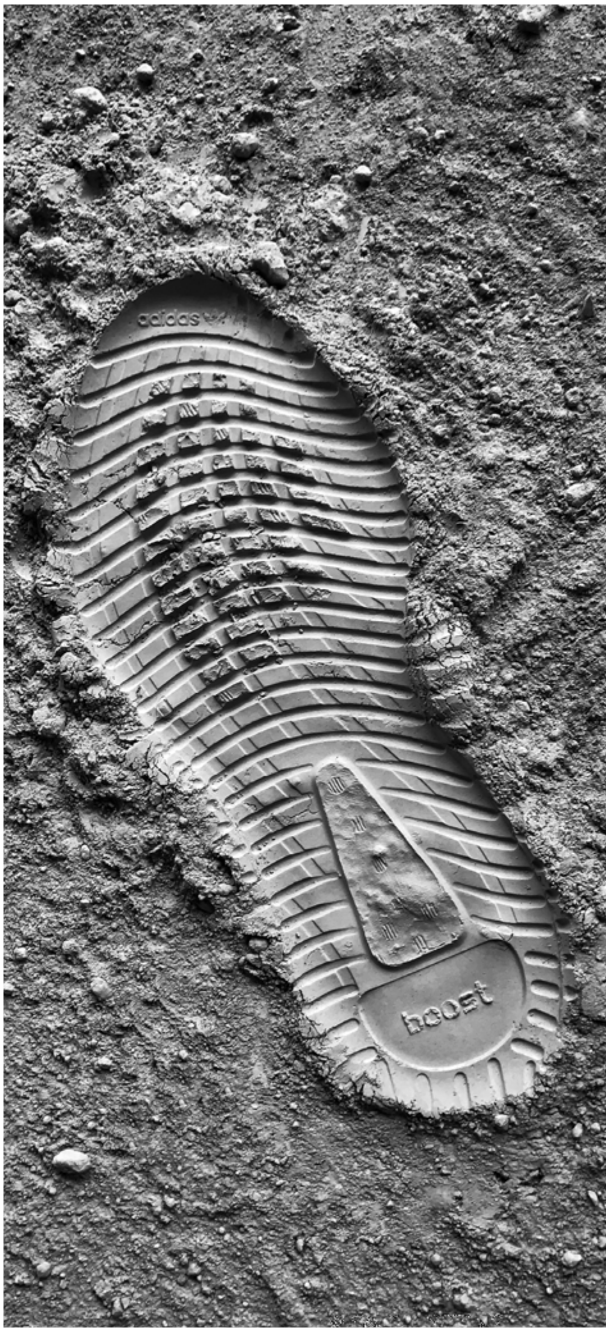
Controlling the clearance and alteration of land and forests for other land uses, including agriculture (crop cultivation and pasture), mining, and infrastructure, among others is critical to controlling the risk of biodiversity loss and ecosystem collapse. Estimates shows that the rate of deforestation has fallen globally by almost a third compared to the previous decade[20].

The development and adoption of new technologies or production models that are less resource-intensive and/or less polluting could reduce the risk of biodiversity loss and ecological collapse, as would a shift towards more sustainable lifestyles, more specifically changing consumption patterns, possibly accompanied by behaviour change[21].

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[23].

Integrating the valuation of ecosystems into economic decision making, reviewing our measures of economic success, and employing robust environmental accounting systems across businesses and national economies would contribute to reducing the risk[23]. The latest assessments reports that over 100 countries have now incorporated biodiversity values into national accounting systems[24].

Global governance mechanisms to conserve ecosystems and reduce pollution, in particular more integrated approaches between the global governance of ecosystems and economics and trade, are of particular importance, as many ecosystems do not overlap with national boundaries, and trade is an important driver of ecosystem collapse[25].



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ECOSYSTEM COLLAPSE IN AUSTRALIA AND TERRESTRIAL ANTARCTICA

A recent study assessed evidence of collapse in 19 ecosystem (both terrestrial and marine) that cover approximately 1.5% of the Earths surface extending from northern Australia to coastal Antarctica, looking at environmental changes over the past 30 years[26]. The study applied four criteria to assess collapse (abrupt, smooth, stepped and fluctuating), and found evidence of local collapse for all the 19 ecosystems studied, although none has collapsed across the entire distribution.

The collapses were as a result of ecosystems experiencing multiple pressures simultaneously, including pressures from global climate change (such as temperature rise, altered precipitation and ocean acidification), and pressures arising from regional human impacts (such as habitat loss, pollution and water extraction) acting together to erode biodiversity. To deal with this challenge of ecosystem collapse, the authors recommend a three-step approach of promoting awareness of ecosystem values, anticipation of pressures, and taking action to manage the impacts through recovery, restoration, renovation and adapting to the changes.

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. 1972 marked a major milestone in global environmental governance with the hosting of the United Nations Conference on Human Environment in Stockholm, Sweden, that culminated into the establishment of the United Nations Environment Program (UNEP) as the anchor institution for the global environment and with the mandate to among others, address global ecological risks[2].

The subsequent period post 1972, witnessed the proliferation of global environmental conventions, also known as treaties or agreements, as the main international legal instrument for promoting collective action toward managing ecological risks. Although the number and membership of these conventions has increased dramatically, an assessment of the implementation of the measures promoted through these treaties reveals a very poor record; since 1972, only about one tenth of the hundreds of global environment and sustainable development targets agreed by countries have been achieved or seen significant progress[3].

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[4]. 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 Climate 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. The United Nations General Assembly Resolution 72/277 on "Towards a Global Pact for the Environment", seeks to explore how to strengthen the implementation of international environmental law, and international environmental governance[5].

Additionally, through the United Nations Convention on Biological Diversity (CBD), UN member states are working on a post-2020 global biodiversity framework to be adopted at the 15th Conference of Parties (CoP) to the CBD.

The framework builds on the Strategic Plan for Biodiversity 2011-2020 and sets out an ambitious plan to implement broad-based action to bring about a transformation in society's relationship with biodiversity and to ensure that, by 2050, the shared vision of living in harmony with nature is fulfilled. The framework aims to galvanize urgent and transformative action by governments and all of society, including indigenous peoples and local communities, civil society and businesses, to achieve the outcomes it sets out in its vision, mission, goals and targets, and thereby contribute to the objectives of the Convention on Biological Diversity and other biodiversity related multilateral agreements, processes and instruments.

Importantly, many countries are implementing their obligations. The Environmental Conventions Index (ECI) 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 determinants of implementation[6]. 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[7].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].

Since the 2015 Paris Agreement, the progress on global efforts to address climate change have been slow, despite the growing threat that climate change and other human activities risk triggering biosphere tipping points across a range of ecosystems and scales[8]. Companies, cities, and countries must raise their ambition to significantly take actions to reduce greenhouse gas emissions to below the 1.5-degree target and lead the transformation to a low carbon economy, which many see as desirable, inevitable, and irrevocable.

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Global population size

WHAT IS AT STAKE?

The total human population has increased dramatically from around 1.6bn in 1900 to 8bn today, and it is forecast to continue growing over the course of the 21st century. A larger human population will—all else equal—place greater stress on most ecological systems and may have adverse consequences for human welfare.

A rapidly growing human population may constitute a global catastrophic risk in that it could threaten human welfare and in particular may reduce the welfare of future generations. A large population may contribute and interact with other global catastrophic risks, e.g., those related to ecological collapse. As such, it may contribute to the “destruction of humanity's long-term potential"[1], making it an existential risk in a weak sense. It is not, however, an existential risk in its strict sense: A risk “... that threatens the premature extinction of Earth-originating intelligent life...”[2]

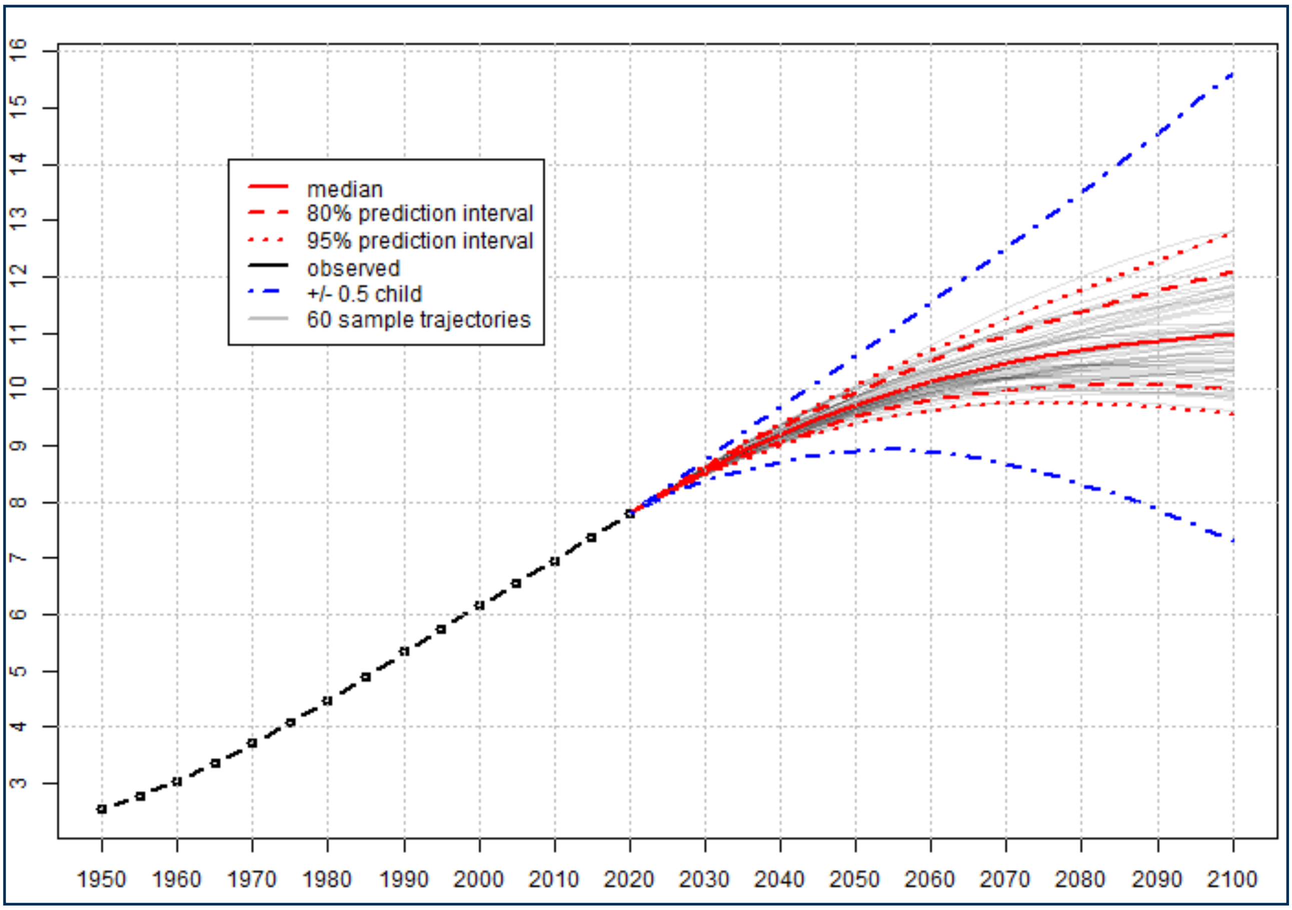
While population growth will not, in itself, threaten our ability to feed a global population or put at risk current civilization, if the global population grows more quickly than societies can adapt, we and future generations may be confronted with very difficult trade-offs, and irreparable harm to the biosphere.

Global population growth is likely to be regionally imbalanced, concentrated in poorer countries. This means that negative externalities of population growth will also be concentrated in poorer countries. That a growing share of the world population in the least well-off countries may contribute to future political challenges such as conflicts and global inequality, which in turn may lead to migration from poorer countries.

HOW MUCH DO WE KNOW?

Demographers and government agencies have reliable information on population statistics and can make high-quality forecasts for the near future. We can be nearly certain that the human population will grow substantially over this century. The UN 2019 Population Prospects have a median forecast of 9.7bn people for 2050 and around 10.9bn for 2100. As much current population growth is due to the young age structure of the global population, these forecasts are rather certain and the UN gives an 80% confidence interval of 9.5—10bn for 2050 and 9.9—12bn for 2100.

Credit/source: Unsplash



This figure shows estimates and probabilistic projections of the total world population, based on projections of total fertility and life expectancy at birth. The lines represent the probabilistic median, and 80 and 95 per cent prediction intervals, as well as the (deterministic) high and low variants.

Most of our uncertainty about future population growth is related to childbearing. There are two major factors whose impact is not yet known: 1) the speed of fertility decline in Sub-Saharan Africa, and 2) future fertility trajectories in middle-income countries in Asia (particularly India and China). Fertility decline in Sub-Saharan Africa has previously been slower than in historic forecasts, though on the other hand the world has several recent historical examples of very rapid fertility decline (e.g. in East and South East Asia). China currently has very low fertility of around 1.3 children per woman, and fertility is rapidly falling in India. Whether the large Asian countries will have childbearing levels comparable to current southern European countries, or more comparable to the higher fertility levels in Anglo-Saxon countries, will be very important for global population trajectories in the 21st century.

There is much less certainty and more scientific debate on the consequences of population growth. The majority of researchers, though not all, foresee negative consequences of very large population sizes, while there is more debate about the positive and negative consequences of population growth in the nearer term.

Some researchers worry about potentially negative impacts of population decline at a national level, though these worries are usually linked to effects on the age structure (the ratio of older individuals to younger individuals) rather than the absolute population size. Insofar as the elderly are an increasing share of the population, that could place a variety of burdens on younger generations.

Most population growth will take place in low-income countries (with incomes per capita below about US$1000/year). But for the next several decades, most externalities of unsustainable consumption are linked to the current (and future) population size in high-income and upper-middle income countries. Thus, a focus on current individuals (contemporary population size and consumption, and their children) puts the focus on high-income countries, while a focus only on changes in population size (e.g. a focus on countries that will see large-scale population growth) puts more of a focus on low-income countries.

In the very long term, it is reasonable to assume that it is the global population size that will determine what is a desirable or sustainable population. However, for this century, most negative externalities of population growth will be concentrated in high-income and upper middle-income countries.

▼ The UN 2019 Population Prospects have a median forecast of 9.7bn people for 2050 and around 10.9bn for 2100 ▼

The consequences of global population growth will be context dependent and depend on current and future policy choices. Where societies make sustainable choices, the environmental consequences of population growth will be relatively smaller. Nevertheless, and especially given humanity's failure to make sufficiently sustainable choices, it is likely that a large global population will mean that future generations will have to make trade-offs between, for example, material welfare, a sustainable eco-sphere, and the well-being of future generations. Such trade-offs will be harder if we greatly value aspects such as untouched wildness and global biodiversity, where a large human population will likely imply negative externalities for the foreseeable future, and a too large population may be associated with irreversible harm. The level of a sustainable global population will eventually be determined by what we as a society value, and what trade-offs we think are reasonable.

WHAT ARE THE KEY FACTORS AFFECTING RISK LEVELS?

- Global population trends are primarily shaped by childbearing. Fertility levels are highest in low-income countries, but fertility levels in middle-income countries (such as India and China) will be at least as influential for Earth's future population.
- Most population growth in the 21st century will take place in low-income countries, but each (living and soon to be born) person in high-income countries contributes more to current negative externalities of a large population size.
- A growing population may make it harder to balance different needs of future human populations, such as affluence, equity and the maintenance of the biosphere. Sustainable policy choice may reduce the need to make such trade-offs.

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Governance of global population size

Population size is seen as a strictly national concern, and there exists no super-national organization or global treaty with a mandate to regulate either national or global population size. There exists no global consensus on, or governance of, what a desirable level of childbearing is; instead there is considerable diversity in the policies and goals of different countries.

At the national level, different countries pursue very different population trajectories, where some countries spend considerable resources on reducing childbearing levels, while other countries implement polices to increase it. Since the 1970s, member countries of the UN report their population policies to the UN population division. They are asked if they had policies to support higher or lower fertility.

In 2016, of the 192 countries in the world 28% reported that they wanted to increase fertility, 15% that they wanted to maintain it, 42% that they wanted to lower it, and 15% reported that they had no official policy. In Europe, 66% reported that they wanted to increase fertility, while no countries reported that they wanted to lower it. In Africa 83% of countries wanted to reduce fertility, while 4% wanted to increase it. All countries that wanted to reduce fertility had childbearing above 2 children per women, and nearly all countries that wanted to increase it had fertility below 2.

However, some Asian countries had fertility above 2, and still reported they wanted to increase it. Nearly all countries report policies both to support family planning, for example by making contraceptives available (which has the potential to lower population growth), and most countries – including nearly all high-income countries – report having child and/or family allowances (which has the potential to support growth).

During the 20th century, many developing countries sought to reduce population growth, and this was in many contexts encouraged and supported by western NGOs and aid agencies. Where they took place in countries with weaker human rights and checks, such programs were associated with substantial human-rights abuses, for example in India and China. Today, several international organizations and some parts of the UN system continue to promote family planning programs in low-income countries, though there is a strong focus on female empowerment and meeting unmet needs/desires for contraceptives. Conversely, some states and inter-governmental organizations in rich countries—such as the European Union—instead fund programs with the aim of increasing population growth. In conclusion, there exist no unified governance for either population growth or a sustainable global population size.

Reviewed by
MAGNUS JIBORN

Climate tipping points

The Thwaites Glacier is a giant river of ice, more than a kilometer deep at its base and covering an area roughly the size of Britain, that is slowly flowing from the interior of the West Antarctic Ice Sheet to the Amundsen Sea in the South Pacific Ocean.

Right next to it is the Pine Island Glacier, another enormous ice flow, transporting ice masses formed in the interior of West Antartica over millennia towards the ocean. Together the two glaciers hold enough frozen water to raise the global sea level by more than a meter if they melt. And melting they are.

Due to global heating, the Thwaites and Pine Island Glaciers have been shrinking for decades, losing billions of tons of ice every year, with a combined net ice loss currently corresponding to a 0.3 mm global sea level rise per year.

Now, 0.3 mm per year may not sound too alarming, and if glacier melting was a linear process, it could take hundreds or thousands of years before the two glaciers would cause any serious trouble for the world. Unfortunately, that is not how things work.

The Thwaites and Pine Island glaciers are both grounded at bedrock deep below the surface of the sea, and as the glaciers slowly shrink, they become increasingly exposed to the ocean, causing accelerating melting from below, undermining the glaciers and causing them to slide faster into the ocean.

At some point, this process of disintegration from below could become self-sustaining and continue to escalate, even if the man-made global heating that triggered it was halted. Eventually the ice shelves, and then the entire glaciers, may collapse and, in turn, destabilize the entire West Antarctic Ice Sheet.

The critical threshold where glacier decay turns into a self-reinforcing process, with ice loss triggering further ice loss in an accelerating spiral towards large scale ice sheet collapse, constitutes what scientists have identified as a climate tipping point.

The existence of such tipping points in the Earth's climate system has caused increasing alarm among climate scientists, since it means that disastrous and irreversible consequences of global heating could occur much faster and with less heating than previously thought.


Credit/source: Unsplash

A particularly important, and scary, insight is that the tipping point is not the point when the glacier collapses; it is the point when the self-sustaining process that may eventually lead to glacier collapse is set in motion. This could happen decades before the collapse and perhaps without anyone noticing.

In physics – where the concept has its origins – a tipping point is the maximum angle to which you can tilt an object before it tips over. Within a certain range – as long as the center of gravity stays within its support base – an object that is tilted remains stable. But – as some of us have experienced as school children – if you lean backwards on your chair beyond a certain angle, it will tip over and you end up flat on your back at the floor.

The concept has gained a much wider use and is today applied to explain change dynamics in a variety of scientific disciplines: sociology, game theory, economics, epidemiology, ecology. In climate science, the concept is used to identify dangerous thresholds where anthropogenic global warming could trigger dramatic, self-reinforcing and possibly irreversible changes in vital, life supporting systems of the earth.

In addition to the West Antarctic Ice Sheet, potential tipping elements in the climate system include the Amazon, where deforestation, droughts and fires may cause a massive loss of forest, causing further forest loss in a vicious spiral, turning one of the world's largest carbon sinks into a giant carbon source. It also includes ocean circulation systems, dying coral reefs and thawing permafrost in arctic regions that could release vast amounts of stored carbon to the atmosphere, making climate change continue, and accelerate even if human emissions would go to zero.

The generalized tipping point concept involves

1. A system with multiple possible, qualitatively different, alternative states, that is stable in the sense that some external force is required to push the system out of its incumbent state.
2. A positive feedback mechanism that, beyond the tipping point, becomes strong enough to continue to move the system away from its initial state even if the external forcing is removed.

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In the case of a tilted chair, the positive feedback mechanism is gravity; in the case of thawing permafrost, it is the fact that the carbon released from frozen organic material will add to and accelerate global heating, thus causing additional thawing, releasing even more carbon to the atmosphere. Positive feedback mechanisms typically generate exponential change, starting off slowly but then accelerating. This means we may at first underestimate the magnitude of an emerging problem grossly and fail to react adequately while we still have time to make a real difference.

To give an idea of the power of exponential change, suppose you had a choice between 10 million USD today, or 10 cents to be doubled every week. What would you choose? Well, if you choose the 10 cents, you will at first see your small fortune grow very slowly, almost unnoticeable, for many weeks. After five weeks you could perhaps buy a cappuccino. After 15 weeks your money will have started to grow, but you will still be lagging far behind with around 3,000 USD on your account. But within less than a year your initial 10c will have turned into an amount exceeding global GDP.

Understanding that neither global heating nor the impacts of it are linear processes, but characterized by complex feedback mechanisms, exponential change and critical tipping points, comes with some important policy implications. First and foremost, it means that action is extremely urgent; it is before tipping points are crossed that we can change the course of history, not when the effects of crossing them unfold before us.

But it also means that we may have more power to change our destiny than we realize. The existence of "positive tipping points"[1] in social and economic change may provide us with powerful opportunities for rapid changes of human behavior, technologies and patterns of production and consumption that are needed for a transition towards a sustainable future.

Social tipping points occur in human interaction problems where people have incentives to behave in the same way as others. In 'A Discourse on Inequality', Jean Jacques Rousseau tells a much cited, brief anecdote about an imaginary hunter society where people can choose to collaborate to hunt deer, or to hunt hare on their own:

> **▼If it was a matter of hunting a deer, everyone well realized that he must remain faithful to his post; but if a hare happened to pass within reach of one of them, we cannot doubt that he would have gone off in pursuit of it without scruple...[2]▼**

Suppose that catching a deer together brings more meat to the table for all than each catching a hare by themselves, and that the chance of catching a deer increases with the number of hunters who collaborate. The situation has two equilibrium outcomes: a collaborative one where all hunt deer, and a non-collaborative one where all hunt hares. In game theory, this type of interaction problem is known as the Stag Hunt[3].

Since the collaborative equilibrium is better for all, deer hunting might seem to be the obvious choice. However, deer hunting is also risky; if you hunt deer and everyone else leave their posts to go hare hunting, you will go to sleep hungry. If you live in a society where everyone hunts hare, you better do the same. A society can therefore be trapped in a non-collaborative equilibrium that is bad for all.

The problem illustrated by the Stag Hunt game is how a society can transition from a bad equilibrium to a better one. The tipping point is where a critical mass of hunters start working together, making it beneficial for others to join them, which increases the attraction of collaboration further.

Right now, humanity is facing a giant challenge with a similar structure: How can we collectively move from the current state, trapped in fossil fuel dependence, overconsumption of resources and unsustainable take-make-waste production models towards a future of renewable energy, and sustainable modes of consumption and production?

Many aspects of this necessary transition have a Stag Hunt-structure. We start from a state of deep dependence on fossil fuels, where the incumbent fossil-based solutions benefit from economies of scale, sunk costs and infrastructure – roads, grids, fueling stations – that has been built around and adapted to the existing fossil solutions since decades.

Any alternative technology – renewable energy, electric vehicles or circular production – will start off at a disadvantage. But as the market share of the alternative solution grows, costs will go down, infrastructure will be built to support it, and it will become more and more competitive both in terms of cost and availability. At some point, the alternative solution may become cheaper and more easily available than the incumbent one.

That is the tipping point. That is the point where the market starts to transform by itself at an accelerating pace, without policy interventions. There are signs that some tipping points have been passed; on many markets, wind and solar power is already less expensive than new – or even existing – coal power.

This means that well targeted, well-designed and timely policy interventions can have much more impact than we acknowledge. One important role of policy interventions is simply to push potentially viable sustainable solutions beyond the hilltop, where the carriage start rolling by itself.

Understanding the power of exponential change and tipping points thus should make us both scared and determined: the situation is likely much worse than we can currently see, but our power to do something about it is also much greater than we realize.

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