Global Challenges

12 Risks that threaten human civilisation

The case for a new risk category

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Executive Summary

This is the executive summary of a report about a limited number of global risks that pose a threat to human civilisation, or even possibly to all human life.

With such a focus it may surprise some readers to find that the report's essential aim is to inspire action and dialogue as well as an increased use of the methodologies used for risk assessment. The real focus is not on the almost unimaginable impacts of the risks the report outlines. Its fundamental purpose is to encourage global collaboration and to use this new category of risk as a driver for innovation.

The idea that we face a number of global challenges threatening the very basis of our civilisation at the beginning of the 21st century is well accepted in the scientific community, and is studied at a number of leading universities.[I] *But there is still no coordinated approach to address this group of challenges and turn them into opportunities.*

[I] http://en.wikipedia.org/wiki/Global_catastrophic_risk

History: the LA-602 document

It is only 70 years ago that Edward Teller, one of the greatest physicists of his time, with his back-of-the-envelope calculations, produced results that differed drastically from all that had gone before.His calculations showed that the explosion of a nuclear bomb – a creation of some of the brightest minds on the planet, including Teller himself – could result in a chain reaction so powerful that it would ignite the world's atmosphere, thereby ending human life on Earth.

Robert Oppenheimer, who led the Manhattan Project to develop the nuclear bomb, halted the project to see whether Teller's calculations were correct. The resulting document, LA-602: Ignition of the Atmosphere with Nuclear Bombs, concluded that Teller was wrong. But the sheer complexity drove the assessors to end their study by writing that "further work on the subject [is] highly desirable". The LA-602 document can be seen as the first global challenge report addressing a category of risks where the worst possible impact in all practical senses is infinite.

12 Global risks

This report has, to the best of the authors' knowledge, created the first list of global risks with impacts that for all practical purposes can be called infinite. It is also the first structured overview of key events related to such challenges and has tried to provide initial rough quantifications for the probabilities of these impacts.

The report conducts its exploration within carefully defined bounds, resulting in a list of twelve risks with a possible infinite outcome

There were many challenges which might have been included on the list because of their ability to pose severe damage to humanity. They were excluded for one or more of three reasons:

1. Limited impact – tsunamis, for example, and chemical pollution.

2. No effective countermeasures – the report focuses on promoting effective interventions and so ignores challenges where nothing useful can be done to prevent or mitigate the impact, as with nearby gamma-ray bursts.

3. Included in other challenges. Many challenges are already covered by others, or are very similar to them. Population growth, for one, is significant for climate change and ecosystem catastrophe, but without direct large-scale impacts of its own.

It is worth noting that complex systems are often stable only within certain boundaries outside which the system can collapse and rapidly change to a new stable state. Such a collapse can trigger a process where change continues for a long time until a new stable state is found. None of the risks in this report is likely to result directly in an infinite impact, and some cannot do so physically. All the risks however are big enough to reach a threshold where the social and ecological systems become so unstable that an infinite impact could ensue.

This is a report about two extremes, not one. It is about how a better understanding of the magnitude of the challenges can help the world to address the risks it faces, and can help to create a path towards more sustainable development. It is a scientific assessment about the possibility of oblivion, certainly, but even more it is a call for action based on the assumption that humanity is able to rise to challenges and turn them into opportunities. We are confronted with possibly the greatest challenge ever and our response need to match this thorough global collaboration in new and innovative ways.

Extreme Climate Change

Nuclear War

Global Pandemic

Ecological Catastrophe

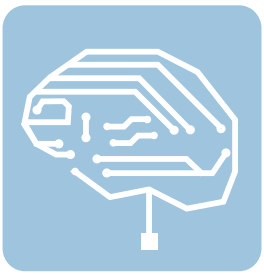
Global System Collapse

Major Asteroid Impact

Super-volcano

Synthetic Biology

Nanotechnology



Artificial Intelligence

Unknown Consequences

Future Bad Global Governance

The goals of the report

The four main goals of this report are to acknowledge, inspire, connect and deliver.

The first of the report's goals – acknowledging the existence of risks with potential infinite impact – seeks to help key stakeholders to acknowledge the existence of the category of risks that could result in infinite impact and to show them that we can reduce or even eliminate most of them.

The second inspires by showing the practical action that is taking place today. This report seeks to show that helping to meet these global challenges is perhaps the most important contribution anyone can make today, and highlights concrete examples to inspire a new generation of leaders.

The third goal is to connect different groups at every level, so that leaders in different sectors connect with each other to encourage collaboration. This will need a specific focus on financial and security policy where significant risks combine to demand action beyond the incremental.

The fourth goal is to deliver actual strategies and initiatives that produce actual results. The report is a first step and its success will ultimately be measured only on how it contributes to concrete results.

The report will have achieved its goals when key decision-makers recognise the magnitude of the possible risks and our ability to reduce or even eliminate most of them.

The goals

1. *to acknowledge the existence of risks with potential infinite impact*
2. *to inspire by showing the practical action that is taking place today.*
3. *to connect different groups at every level.*
4. *to deliver actual strategies and initiatives that produce actual results.*

Report structure

The first part of the report introduces and defines the global challenges and includes the methodology for selecting them.

The second part is an overview of the twelve challenges and key events that illustrate strategic work to address them. It also lists for each challenge five important factors that influence its probability or impact. The challengesare divided into four different categories:

– current challenges includes those which currently threaten humanity because of its economic and technological development;

– exogenic challenges are those where the basic probability of an event is beyond human control, but where the probability and magnitude of the impact can be influenced;

– emerging challenges could both help to reduce the risks associated with current challenges and also result in infinite impacts;

– the last of the twelve is defined as a global policy challenge, a threat arising from future global governance as it resorts to destructive policies in response to the categories of challenge listed above.

The third part of the report discusses the relationship between the different challenges, because action to address one can increase the risk of another. Many solutions can also address multiple challenges, so there are significant benefits from understanding how they are linked.

The fourth part is an overview, the first ever to the authors' knowledge, of the probabilities of global challenges with potential infinite impacts.

The fifth presents some of the most important underlying trends that influence the challenges, which often build up slowly to a threshold where very rapid changes can ensue.

The sixth part presents an overview of possible ways forward.

A new category of global risk

The idea that there may be risks where the impact can be described as infinite, defined as the end of human civilisation or even human life, is not new. However, it excites relatively little political or academic interest and the way it is treated in popular culture makes a serious discussion harder.

For several reasons the potentially infinite impacts of the challenges in this report are not as well known as they should be. One reason is the way that extreme impacts are often masked by most of the theories and models used by governments and business today.

Climate change is a good example, where almost all of the focus is on the most likely scenarios and there are few public studies that include the low-probability high-impact scenarios. In most reports about climate impacts, those caused by warming beyond five or six degrees Celsius are omitted from tables and graphs. Other aspects that contribute to this relative invisibility include the fact that extreme impacts are difficult to translate into monetary terms, they have a global scope, and they often require a time-horizon of a century or more. They cannot be understood simply by linear extrapolation of current trends, and they lack historical precedents. There is also the fact that the measures required to significantly reduce the probability of infinite impacts will be radical compared to a business-as-usual scenario.

A scientific approach requires us to base our decisions on the whole probability distribution.

The review of literature indicate that, under a business as usual scenario, new risks with potential infinite impact is probably inseparable from the rapid technological development in areas like synthetic biology, nanotechnology and AI.

Most risks are linked to increased knowledge, economic and technical development that has brought many benefits. E.g. climate change is a result from the industrial revolution and fossil fuelbased development. The increased potential for global pandemics is one consequence of an integrated global economy where goods and services move quickly internationally. Similar challenges can be expected for synthetic biology, nanotechnology and AI.

There are remedies, including technological and institutional, for all risks. But they will require collaboration of a sort humanity has not achieved before, and the creation of systems which can deal with problems pre-emptively. It is important to understand that much of the knowledge and many tools that we have, and will develop, can be both a risk and a solution to risks depending on context.

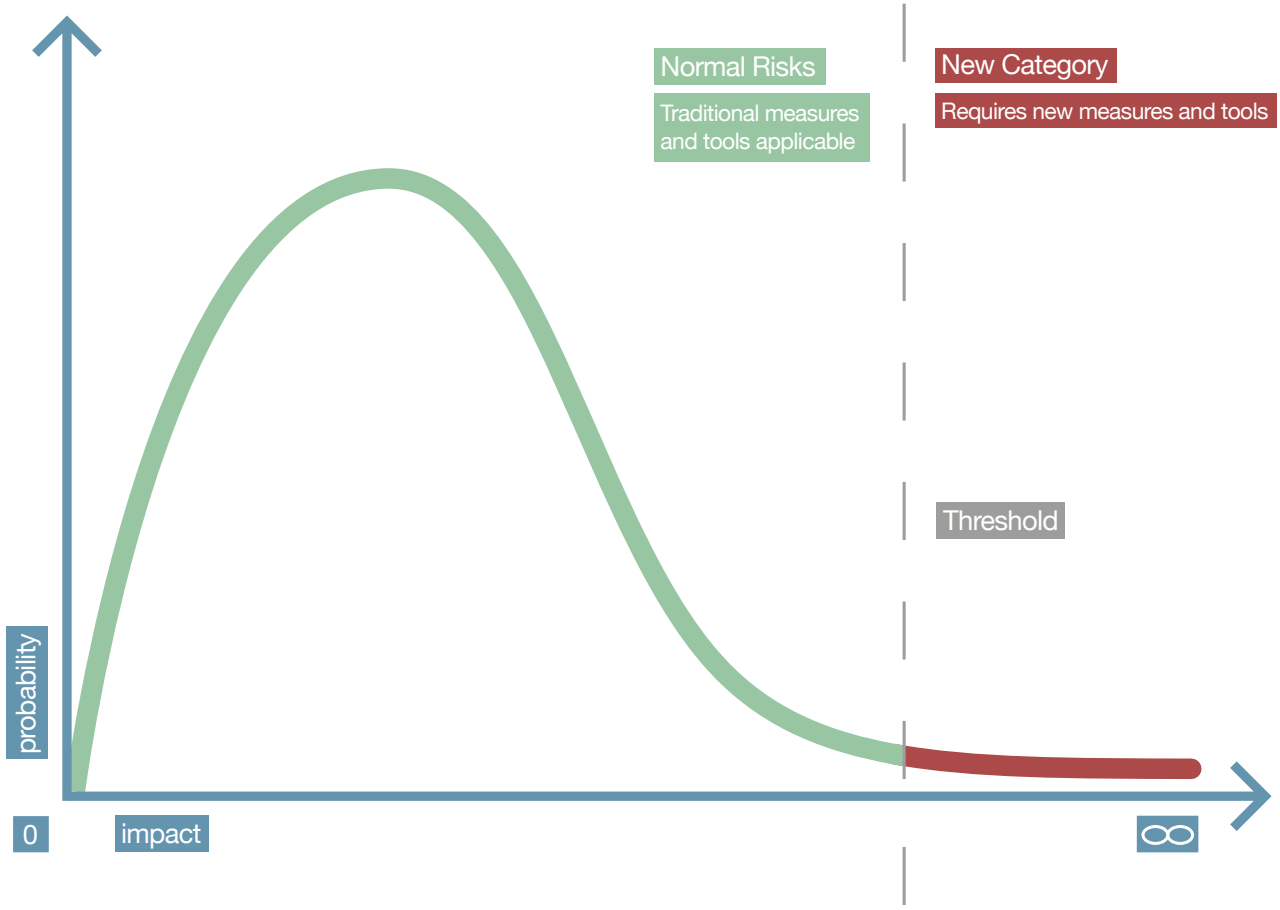
Infinite impacts and thresholds

There is a clear ethical dimension to the concept of infinite impact, because a very small group alive today can take decisions that will fundamentally affect all future generations.

Its equally clear economic component can generate disagreement over issues such as discounting, which the report examines in some detail,considering for example the role of tipping points.

The report distinguishes between the concepts of infinite impact – where civilisation collapses to a state of great suffering and do not recover, or a situation where all human life end – and infinite impact threshold – an impact that can trigger a chain of events that could result first in a civilisation collapse, and then later result in an infinite impact. Such thresholds are especially important to recognise in a complex and interconnected society where resilience is decreeing.

A collapse of civilisation is defined as a drastic decrease in human population size and political/ economic/social complexity, globally for an extended time.



Methodology

In order to establish a list of global challenges with potential infinite impact a methodological triangulation was used, consisting of:

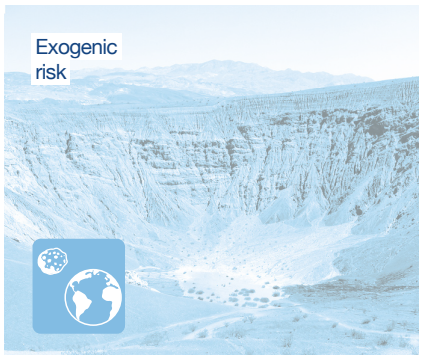
– A quantitative assessment of relevant literature.

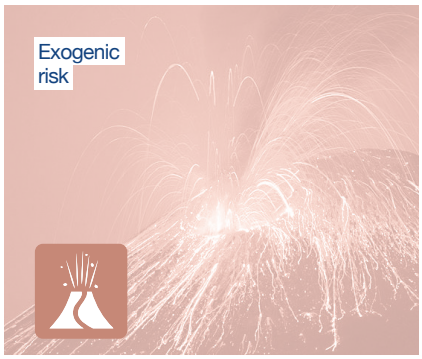
– A strategic selection of relevant organisations and their priorities.

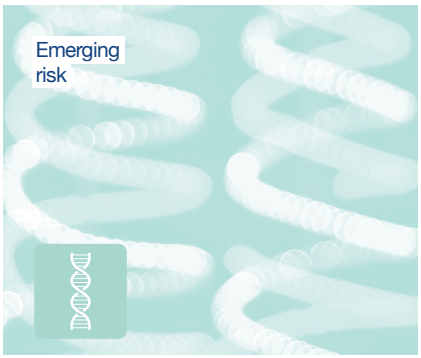
– A qualitative assessment with the help of expert workshops.

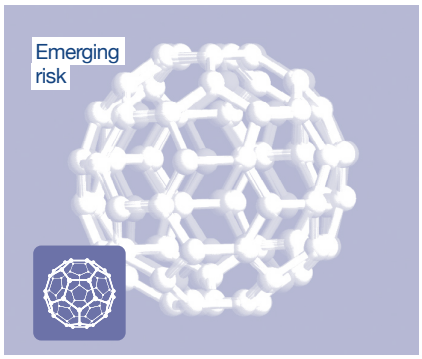
Two workshops were arranged where the selection of challenges was discussed, one with risk experts in Oxford at the Future of Humanity Institute and the other in London with experts from the financial sector. No challenge was excluded at the workshops, but one was added: the participants agreed to include Global System Collapse as a category.

Quick overview of each risk









Current risk

5 key factors:

1. The uncertainties in climate sensitivity models, including the tail.
2. The likelihood - or not - of global coordination on controlling emissions.
3. The future uptake of low carbon economies, including energy, mobility and food systems.
4. Whether technological innovations will improve or worsen the situation, and by how much.
5. The long-term climate impact caused by global warming.

Extreme Climate Change

As for all risks there are uncertainties in the estimates, and warming could be much more extreme than the middle estimates suggest. Feedback loops could mean global average temperatures increase by 4°C or even 6°C over pre-industrial levels. Feedbacks could be the release of methane from permafrost or the dieback of the Amazon rainforest. The impact of global warming would be strongest in poorer countries, which could become completely uninhabitable for the highest range of warming.

Mass deaths and famines, social collapse and mass migration are certainly possible in this scenario. Combined with shocks to the agriculture and biosphere-dependent industries of the more developed countries, this could lead to global conflict and possibly civilisation collapse. Further evidence of the risk comes from signs that past civilisation collapses have been driven by climate change.

Current risk

5 key factors:

1. How relations between current and future nuclear powers develop.
2. The probability of accidental war.
3. Whether disarmament efforts will succeed in reducing the number of nuclear warheads.
4. The likelihood of a nuclear winter.
5. The long-term effects of a nuclear war on climate, infrastructure and technology. A new category of global risk.

Nuclear War

The likelihood of a full-scale nuclear war between the USA and Russia has probably decreased. Still, the potential for deliberate or accidental nuclear conflict has not been removed, with some estimates putting the risk in the next century or so at around 10%. A larger impact would depend on whether or not the war triggered what is often called a nuclear winter or something similar – the creation of a pall of smoke high in the stratosphere that would plunge temperatures below freezing around the globe and possibly also destroy most of the ozone layer. The detonations would need to start firestorms in the targeted cities, which could lift the soot up into the stratosphere. The risks are severe and recent models have confirmed the earlier analysis. The disintegration of the global food supply would make mass starvation and state collapse likely.

Current risk

5 key factors:

1. What the true probability distribution for pandemics is, especially at the tail.
2. The capacity of international health systems to deal with an extreme pandemic.
3. How fast medical research can proceed in an emergency.
4. How mobility of goods and people, as well as population density, will affect pandemic transmission.
5. Whether humans can develop novel and effective anti-pandemic solutions.

Global Pandemic

An epidemic of infectious disease that has spread through human populations across a large region or even worldwide. There are grounds for suspecting that such a high-impact epidemic is more probable than usually assumed. All the features of an extremely devastating disease already exist in nature: essentially incurable (Ebola), nearly always fatal (rabies), extremely infectious (common cold), and long incubation periods (HIV). If a pathogen were to emerge that somehow combined these features (and influenza has demonstrated antigenic shift, the ability to combine features from different viruses), its death toll would be extreme.
The world has changed considerably, making comparisons with the past problematic.Today it has better sanitation and medical research, as well as national and supra-national institutions dedicated to combating diseases. But modern transport and dense human population allow infections to spread much more rapidly, and slums can be breeding grounds for disease.

Current risk

5 key factors:

1. The extent to which humans are dependent on the ecosystem.
2. Whether there will be effective political measures taken to protect the ecosystem on a large scale.
3. The likelihood of the emergence of sustainable economies.
4. The positive and negative impacts on the ecosystems of both wealth and poverty.
5. The long-term effects of an ecological collapse on ecosystems.

Ecological Collapse

This is where an ecosystem suffers a drastic, possibly permanent, reduction in carrying capacity for all organisms, often resulting in mass extinction. Humans are part of the global ecosystem and so fundamentally depend on it. Species extinction is now far faster than the historic rate, and attempts to quantify a safe ecological operating space place humanity well outside it. Many of the problems of ecological degradation interact to multiply the damage and (unlike previous, localised collapses) the whole world is potentially at risk.
It seems plausible that some human lifestyles could be sustained in a relatively ecosystem independent way, at relatively low costs. Whether this can be achieved on a large scale in practice, especially during a collapse, will be a technological challenge and whether it is something we want is an ethical question.

Current risk

5 key factors:

1. Whether global system collapse will trigger subsequent collapses or fragility in other areas.
2. What the true trade-off is between efficiency and resilience.
3. Whether effective regulation and resilience can be developed.
4. Whether an external disruption will trigger a collapse.
5. Whether an internal event will trigger a collapse.

Global System Collapse

An economic or societal collapse on the global scale. The term has been used to describe a broad range of conditions. Often economic collapse is accompanied by social chaos, civil unrest and sometimes a breakdown of law and order. Societal collapse usually refers to the fall or disintegration of human societies, often along with their life support systems. The world economic and political system is made up of many actors with many objectives and many links between them. Such intricate, interconnected systems are subject to unexpected system-wide failures caused by the structure of the network – even if each component of the network is reliable. This gives rise to systemic risk, when parts that individually may function well become vulnerable when connected as a system to a self-reinforcing joint risk that can spread from part to part, potentially affecting the entire system and possibly spilling over to related outside systems. Such effects have been observed in ecology, finance and critical infrastructure such as power grids. The possibility of collapse becomes more acute when several independent networks depend on each other.

Exogenic risk

5 key factors:

1. Whether detection and tracking of asteroids and other dangerous space objects is sufficiently exhaustive.
2. How feasible it is to deflect an asteroid.
3. Whether measures such as evacuation could reduce the damage of an impact.
4. The short- and long-term climate consequences of a collision.
5. Whether our current civilisation could adapt to a post-impact world.

Major Asteroid Impact

Large asteroid collisions – with objects 5 km or more in size – happen about once every twenty million years and would have an energy a hundred thousand times greater than the largest bomb ever detonated. A land impact would destroy an area the size of a nation like Holland. Larger asteroids could be extinction-level events. Asteroid impacts are probably one of the best understood of all risks in this report.

There has been some discussion about possible methods for deflecting asteroids found on a collision course with the planet. Should an impact occur the main destruction will not be from the initial impact, but from the clouds of dust projected into the upper atmosphere. The damage from such an “impact winter” could affect the climate, damage the biosphere, affect food supplies, and create political instability.

Exogenic risk

5 key factors:

1. Whether countries will coordinate globally against super-volcano risk and damage.
2. The predictability of super-volcanic eruptions.
3. How directly destructive an eruption would be.
4. The effectiveness of general mitigation efforts.
5. How severe the long-term climate effects would be.

Super-volcano

Any volcano capable of producing an eruption with an ejecta volume greater than 1,000 km3. This is thousands of times larger than normal eruptions. The danger from super-volcanoes is the amount of aerosols and dust projected into the upper atmosphere. This dust would absorb the Sun's rays and cause a global volcanic winter. The Mt Pinatubo eruption of 1991 caused an average global cooling of surface temperatures by 0.5°C over three years, while the Toba eruption around 70,000 years ago is thought by some to have cooled global temperatures for over two centuries.
The effect of these eruptions could be best compared with that of a nuclear war. The eruption would be more violent than the nuclear explosions, but would be less likely to ignite firestorms and other secondary effects.

Emerging risk

5 key factors:

1. The true destructive potential of synthetic biology, especially the tail risk.
2. Whether the field will be successfully regulated, or successfully manage to regulate itself.
3. Whether the field will usher in a new era of bio-warfare.
4. Whether the tools of synthetic biology can be used defensively to create effective counter measures.
5. The dangers of relying on synthetic biologists to estimate the danger of synthetic biology.

Synthetic Biology

The design and construction of biological devices and systems for useful purposes, but adding human intentionality to traditional pandemic risks. Attempts at regulation or self-regulation are currently in their infancy, and may not develop as fast as research does. One of the most damaging impacts from synthetic biology would come from an engineered pathogen targeting humans or a crucial component of the ecosystem.

This could emerge through military or commercial bio-warfare, bio-terrorism (possibly using dual-use products developed by legitimate researchers, and currently unprotected by international legal regimes), or dangerous pathogens leaked from a lab. Of relevance is whether synthetic biology products become integrated into the global economy or biosphere. This could lead to additional vulnerabilities (a benign but widespread synthetic biology product could be specifically targeted as an entry point through which to cause damage).

Emerging risk

5 key factors:

1. The timeline for nanotech development.
2. Which aspects of nanotech research will progress in what order.
3. Whether small groups can assemble a weapons arsenal quickly.
4. Whether nanotech tools can be used defensively or for surveillance.
5. Whether nanotech tools or weaponry are made to be outside human control.

Nanotechnology

Atomically precise manufacturing, the creation of effective, high-throughput manufacturing processes that operate at the atomic or molecular level. It could create new products – such as smart or extremely resilient materials – and would allow many different groups or even individuals to manufacture a wide range of things. This could lead to the easy construction of large arsenals of conventional or more novel weapons made possible by atomically precise manufacturing.

Of particular relevance is whether nanotechnology allows the construction of nuclear bombs. But many of the world's current problems may be solvable with the manufacturing possibilities that nanotechnology would offer, such as depletion of natural resources, pollution, climate change, clean water and even poverty. Some have conjectured special self-replicating nanomachines which would be engineered to consume the entire environment. The misuse of medical nanotechnology is another risk scenario.

Emerging risk

5 key factors:

1. The reliability of AI predictions.
2. Whether there will be a single dominant AI or a plethora of entities.
3. How intelligent AIs will become.
4. Whether extremely intelligent AIs can be controlled, and how.
5. Whether whole brain emulations (human minds in computer form) will arrive before true AIs.

Artificial Intelligence

AI is the intelligence exhibited by machines or software, and the branch of computer science that develops machines and software with human-level intelligence. The field is often defined as "the study and design of intelligent agents", systems that perceive their environment and act to maximise their chances of success. Such extreme intelligences could not easily be controlled (either by the groups creating them, or by some international regulatory regime), and would probably act to boost their own intelligence and acquire maximal resources for almost all initial AI motivations.

And if these motivations do not detail the survival and value of humanity, the intelligence will be driven to construct a world without humans. This makes extremely intelligent AIs a unique risk, in that extinction is more likely than lesser impacts. On a more positive note, an intelligence of such power could easily combat most other risks in this report, making extremely intelligent AI into a tool of great potential. There is also the possibility of AI-enabled warfare and all the risks of the technologies that AIs would make possible. An interesting version of this scenario is the possible creation of "whole brain emulations", human brains scanned and physically represented in a machine. This would make the AIs into properly human minds, possibly alleviating a lot of problems.

Emerging risk

5 key factors:

1. Whether there will be extensive research into unknown risks and their probabilities.
2. The capacity to develop methods for limiting the combined probability of all uncertain risks
3. The capacity for estimating "out of-model" risks.
4. The culture of risk assessment in potentially risky areas
5. Whether general, non-risk-specific mitigation or resilience measures are implemented.

Unknown Consequences

These represent the unknown unknowns in the family of global catastrophic challenges. They constitute an amalgamation of all the risks that can appear extremely unlikely in isolation, but can combine to represent a not insignificant proportion of the risk exposure. One resolution to the Fermi paradox – the apparent absence of alien life in the galaxy – is that intelligent life destroys itself before beginning to expand into the galaxy. Results that increase or decrease the probability of this explanation modify the generic probability of intelligent life (self-)destruction, which includes uncertain risks. Anthropic reasoning can also bound the total risk of human extinction, and hence estimate the unknown component. Nonrisk-specific resilience and post-disaster rebuilding efforts will also reduce the damage from uncertain risks, as would appropriate national and international regulatory regimes. Most of these methods would also help with the more conventional, known risks, and badly need more investment.

Global Policy risk

5 key factors:

1. How the severity of non-deadly policy failures can be compared with potential casualties.
2. Whether poor governance will result in a collapse of the world system.
3. How mass surveillance and other technological innovations will affect governance.
4. Whether there will be new systems of governance in the future.
5. Whether a world dictatorship may end up being constructed.

Future Bad Global Governance

There are two main divisions in governance disasters: failing to solve major solvable problems, and actively causing worse outcomes. An example of the first would be failing to alleviate absolute poverty; of the second, constructing a global totalitarian state. Technology, political and social change may enable the construction of new forms of governance, which may be either much better or much worse.

Two issues with governance disasters are first, the difficulty of estimating their probability, and second, the dependence of the impact of these disasters on subjective comparative evaluations: it is not impartially obvious how to rank continued poverty and global totalitarianism against billions of casualties or civilisation collapse.

Relations between global risks

Two things make the understanding of the relation between the global risks particularly important.

1. Impacts: The risks are interconnected in different ways. Often the situation resembles a set of dominoes: if one falls, many follow. Even small impacts can start a process where different risks interact.

2. Specific measures to address a risk: Global risks often require significant changes, which will result in situations where measures to reduce the risk in one area affect the probability and/or the impact in other areas, for better or worse.

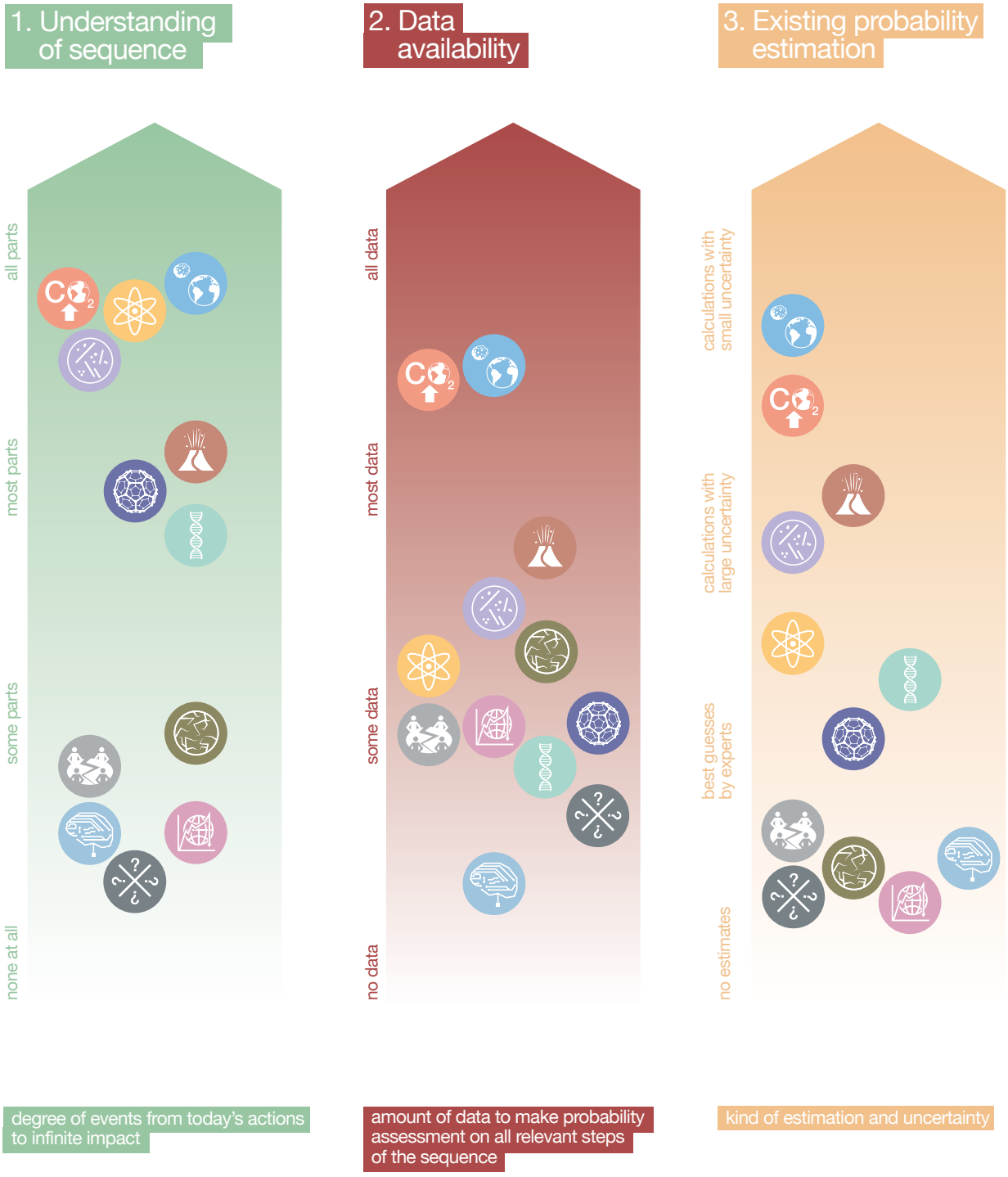
The technical difficulty of reducing the risk and the difficulty of collaboration

In order to better understand the relations between different global risks work could start to analyse similarities and differences.

Below is an example of an overview of how different global risks can be plotted depending on the technical difficulty of reducing the risk and the difficulty of collaborating to reduce it.

Uncertainties

As the different challenges are very different and the status of probability estimates varies significantly, the initial probability numbers are provided together with estimates regarding:



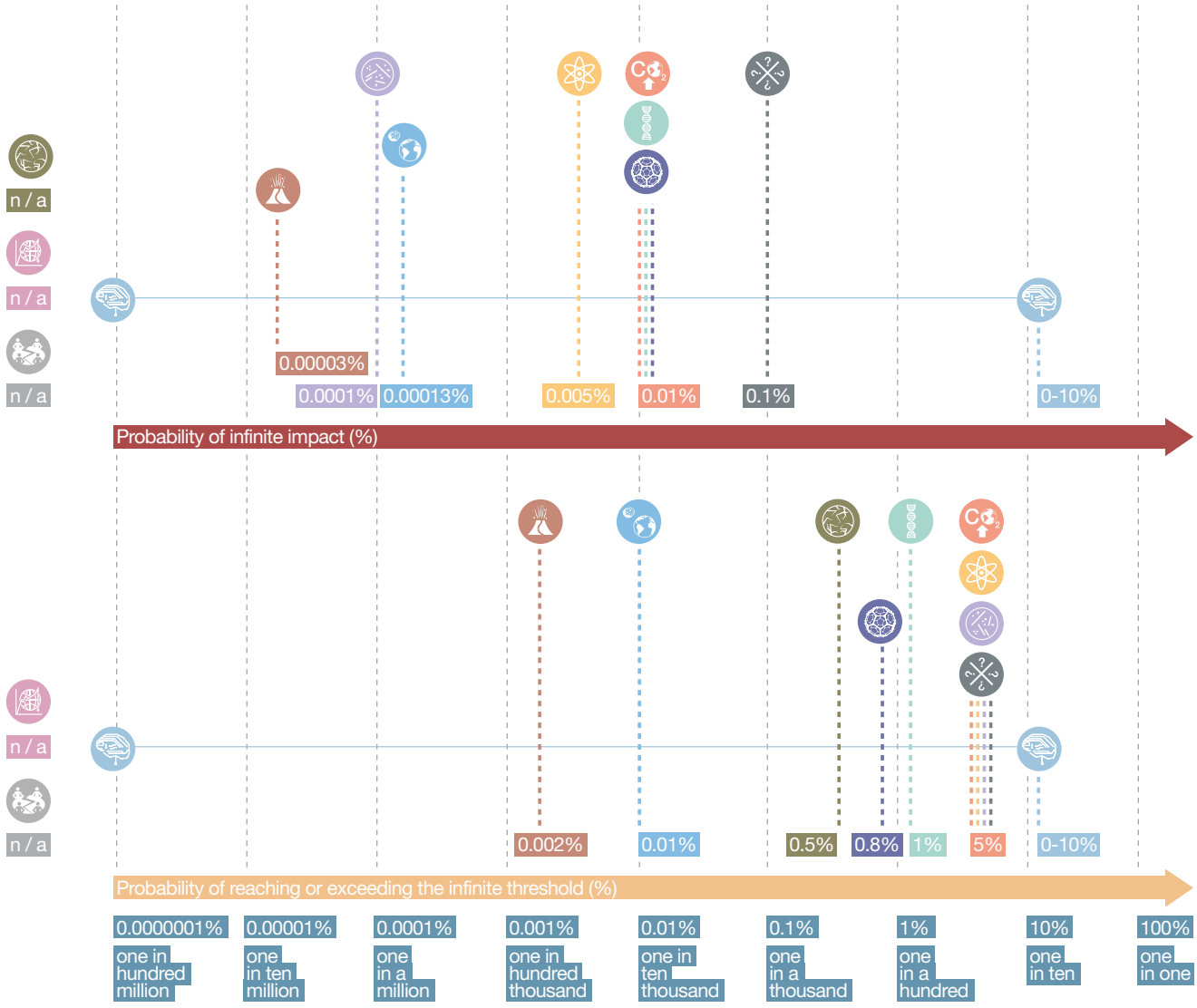
Probability

These estimates are an attempt to assemble existing estimates in order to encourage efforts to improve the numbers. They express estimates of probabilities over 100 years, except in the case of extreme climate change, where the time frame is 200 years.

Global challenges need to be seen in the light of trends which help to shape the wider society. These include:

Poverty – although it has fallen, it could increase again. This is especially relevant to climate change and pandemics.

Population growth – the UN's estimates range from 6.8 billion people by 2100 to a high-variant projection of 16.6 bn (which would require the resources of 10 Earth-like planets to provide everyone with a modern Western lifestyle). Other trends include technological development and demographic changes.



Possible ways forward

There are ten areas that could help mitigate immediate threats while also contributing to a future global governance system capable of addressing global risks with a potential infinite impact:

1. Global challenges leadership networks
2. Better quality risk assessment for global challenges
3. Development of early warning systems
4. Encouraging visualisation of complex systems
5. Highlighting early movers
6. Including the whole probability distribution
7. Increasing the focus on the probability of extreme events
8. Encouraging appropriate language to describe extreme risks
9. Establishing a Global Risk and Opportunity Indicator to guide governance
10. Explore the possibility of establishing a Global Risk Organisation (GRO)

Preface

Over the last century the world has changed in ways that humanity has not experienced in several millennia. The changes are being caused by the extremely rapid development of science and technology, by the population explosion that has quadrupled the number of people on Earth, and by a greatly improved but very resource-demanding standard of living in developed countries.

The consequences of these changes are very diverse:

– Less poverty, better health and longer life in many countries
– Globalisation, whose most important effect is the emergence of a shattered global community where all people's behaviour affects each other's vital interests
– New global risks of previously unseen scope.

This means that we are now forced to live with the risk of various kinds of extreme disaster with the potential of severely affecting billions of people.

In this Yearbook from the Global Challenges Foundation "risk" is defined as the potential damage that can be caused by an extreme disaster multiplied by the probability that it will occur.

For the risk of exceptional damage, the probability of occurrence is usually small, or very small, compared with other risks in society, but the effects can be absolutely dire, meaning they must be taken very seriously.

We do not know the exact nature of these risks are and how they may strike. Some are obvious, others may sound like pure science fiction, but they have led many scientists to regard them as real threats - and therefore it is best to include them in the calculations.

With few exceptions, humans have created these risks. There are only a few risks were we are not the cause, for example natural disasters like an asteroid impact.

We could eliminate some of these risks (e.g. nuclear war). In other cases, all we can do is minimise the likelihood of damage, since we have already crossed the threshold that can lead to serious consequences (with climate change, for example, where we have already emitted such high levels of greenhouse gases that there are small but not insignificant likelihoods of significant damage). For other risks we cannot affect the likelihood of them occurring, only minimise its damage (with super-volcanic eruptions, for instance). However, here we can build social and ecological resilience so as to reduce the damage.

For decisions concerning countermeasures the first important question is: What level of probability of global catastrophes are we prepared to accept? This question has not yet appeared on the political agenda. The reason is that both scientific reports and the media choose to focus on the most likely outcome of these risks.

In the absence of risk analysis both decision-makers and the public remain blissfully unaware that the probabilities of certain global catastrophes are significantly higher than we would accept in our everyday lives, where incomparably smaller values are at stake. Another, very important reason for not acting against acknowledged global risks is that they require global responses and therefore global decisions.

Regrettably there is no global decision-making body capable of that, no globally functioning legal system, and so there is a lack of effective tools for dealing with these challenges. The result: the risks are increased in the absence of effective measures to counter them.

This report wants, on a strictly scientific basis, to identify and describe the global risks of extreme disasters, and also to report the latest developments affecting these risks and measures to face up to them.

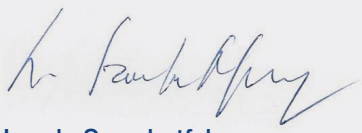
The Global Challenges Foundation's goal in this report is to accelerate effective counter-actions against global events with the potential for large-scale unwanted effects by deepening both decision makers' and the public's insights into the risks, and also to inspire both debate and well-judged decisions on these questions:

– What probabilities of extreme disasters are acceptable?
– Which are the optimal countermeasures?
– How can an effective global decision-making system be created - with or without a global legal system?

We are also convinced that knowledge of these risks is not only a prerequisite for reducing them, but also a responsibility which we owe to our children, grandchildren and to all future generations. It is up to us to decide whether these threats can possibly be reduced or not! These efforts do not only demand sacrifices on our part. They also create opportunities for everyone to make a significant contribution to improving the future of humanity:

– For world leaders this means assuming their responsibility and starting to work towards common, global decision-making.
– Scientists need to focus their research on areas that will help us take effective measures against the risks.
– Companies should make sustainability a business model.
– And there is a special opportunity for all of us - that when choosing our politicians and suppliers (of goods and services), we should consider their ambition to eliminate or at least minimise global risks and to create an efficient decision-making system that can manage these risks.

Finally, I would on behalf of the Global Challenges Foundation extend my sincere gratitude to both Dennis Pamlin, editor of the report, and to all the scientists and other experts who have contributed their research and / or valuable comments.



Laszlo Szombatfalvy
Founder and Chairman,
The Global Challenges Foundation

1. Twelve risks that threaten human civilisation

“Tell me, and I’ll forget.
Show me, and I may remember.
Involve me, and I’ll understand“

Xunzi

不闻不若闻之，闻之不若见之，见之不若知之，
知之不若行之，学至于行之而止矣。荀子

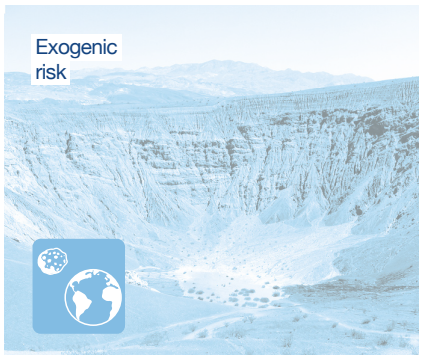

Current
risk

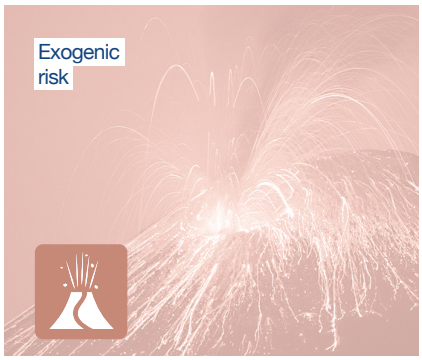

Current
risk

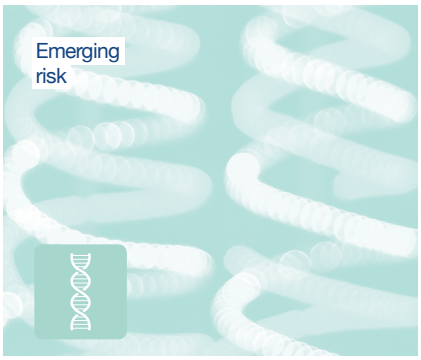

Current
risk

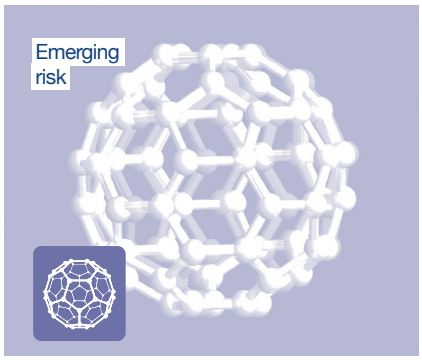

Current
risk


Current
risk


Exogenic
risk


Exogenic
risk


Emerging
risk


Emerging
risk


Emerging
risk


Emerging
risk


Global Policy
risk

2. Risks with infinite impact: A new category of risks

"Most risk management is really just advanced contingency planning and disciplining yourself to realise that, given enough time, very low probability events not only can happen, but they absolutely will happen."

Lloyd Blankfein,
Goldman Sachs CEO,
July 2013 [1]

A new group of global risks

This is a report about a limited number of global risks – that can be identifies through a scientific and transparent process – with impacts of a magnitude that pose a threat to human civilisation, or even possibly to all human life.

With such a focus it may surprise some readers to find that the report's essential aim is to inspire action and dialogue as well as an increased use of the methodologies used for risk assessment.

The real focus is not on the almost unimaginable impacts of the risks the report outlines. Its fundamental purpose is to encourage global collaboration and to use this new category of risk as a driver for innovation.

The idea that we face a number of global challenges threatening the very basis of our civilisation at the beginning of the 21st century is well accepted in the scientific community, and is studied at a number of leading universities.[2]

But there is still no coordinated approach to address this group of challenges and turn them into opportunities for a new generation of global cooperation and the creation of a global governance system capable of addressing the greatest challenges of our time.

This report has, to the best of our knowledge, created the first science based list of global risks with a potentially infinite impact where we in extreme cases all human life could end and has made the first attempt to provide initial overview of the uncertainties related to these risks as well as rough quantifications for the probabilities of these impacts.

What is risk?

Risk is the potential of losing something of value, weighed against the potential to gain something of value. Every day we make different kinds of risk assessments, in more or less rational ways, when we weigh different options against each other.

The basic idea of risk is that an uncertainty exists regarding the outcome and that we must find a way to take the best possible decision based on our understanding of this uncertainty.[3]

To calculate risk the probability of an outcome is often multiplied by the impact. The impact in turn is in most cases measured in economic terms, but it can also be measured in anything we want to avoid, such as suffering.

At the heart of a risk assessment is a probability distribution, often described by a probability density function[4]; see figure X for a graphic illustration.

Risk = Probability × Impact

Impacts where civilisation collapses to a state of great suffering and do not recover, or a situation where all human life end, are defined as infinite as the result is irreversible and lasts forever.

The slightly tilted bell curve is a common probability distribution, but the shape differs and in reality is seldom as smooth as the example.

The total area under the curve always represents 100 percent, i.e. all the possible outcomes fit under the curve. In this case (A) represents the most probable impact. With a much lower probability it will be a close to zero impact, illustrated by (B). In the same way as in case B there is also a low probability that the situation will be very significant, illustrated by (C).

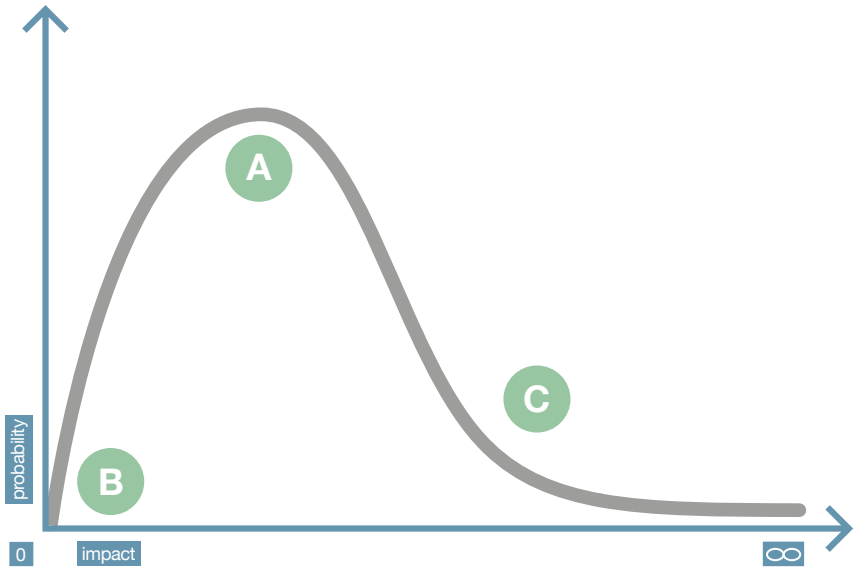


Figure 1:Probability density function

The impacts (A), (B) and (C) all belong to the same category, normal impacts: the impacts may be more or less serious, but they can be dealt with within the current system.

The impacts in this report are however of a special kind. These are impacts where everything will be lost and the situation will not be reversible, i.e challenges with a potentially infinite impact

In insurance and finance this kind of risk is called “risk of ruin”, an impact where all capital is lost.[5] This impact is however only infinite for the company that is losing the money. From society’s perspective, that is not a special category of risk.

In this report the focus is on the “risk of ruin” on a global scale and on a human level, in the worst case this is when we risk the extinction of our own species.

On a probability curve the impacts in this report are usually at the very far right with a relatively low probability compared with other impacts, illustrated by (D) in Figure X+1.

Often they are so far out on the tail of the curve that they are not even included in studies.

For each risk in this report the probability of an infinite impact is very low compared to the mos likely outcome. Some studies even indicate that not all risks in this report can result in an infinite impact. But a significant number of peer-reviewed reports indicate that those impacts not only can happen, but that their probability is increasing due to unsustainable trends.

The assumption for this report is that by creating a better understanding of our scientific knowledge regarding risks with a potentially infinite impact we can inspire initiatives that can turn these risks into drivers for innovation.

Not only could a better understanding of the unique magnitude of these risks help address the risks we face,it could also help to create a path towards more sustainable development.

The group of global risks discussed in this report are so different from most of the challenges we face that they are hard to comprehend.

But that is also why they can help us to build the collaboration we need and drive the development of further solutions that benefit both people and the planet.

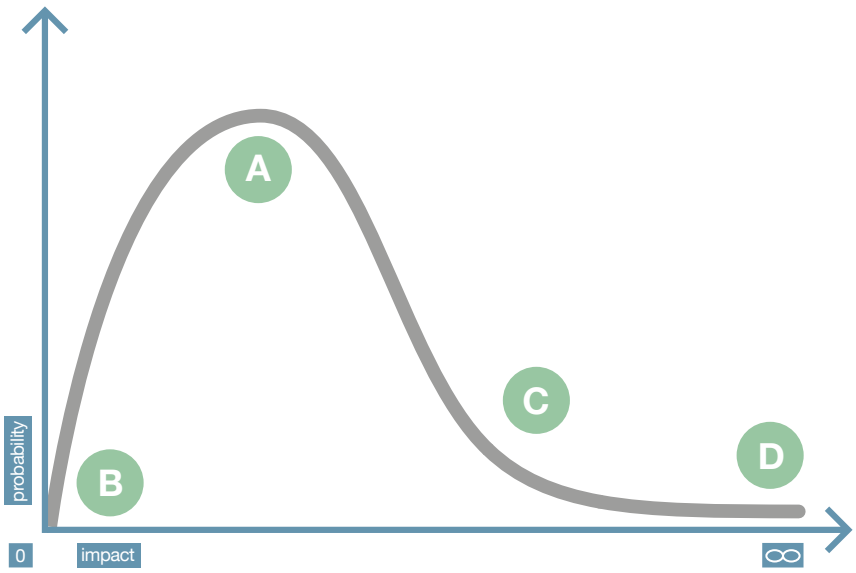
As noted above, none of the risks in this report is likely to result directly in an infinite impact, and some are probably even physically incapable of doing so. But all are so significant that they could reach a threshold impact able to create social and ecological instability that could trigger a process which could lead to an infinite impact.

For several reasons the potentially infinite impacts of the risks in this report are not as well known as they should be. One reason is the way that extreme impacts are often masked by most of the theories and models used by governments and business today.

For example, the probability of extreme impacts is often below what is included in studies and strategies.

The tendency to exclude impacts below a probability of five percent is one reason for the relative “invisibility” of infinite impacts. The almost standard use of a 95% confidence interval is one reason why low-probability high-impacts are often ignored.[6]

Figure 2: Probability density function with tail highlighted



Climate change is a good example, where almost all of the focus is on the most likely scenarios and there are few studies that include the low-probability high-impact scenarios. In most reports about climate impacts, the impacts caused by warming beyond five or six degrees Celsius are even omitted from tables and graphs even though the IPCC own research indicate that the probability of these impacts are often between one and five percent, and sometimes even higher.[7]

Other aspects that contribute to this relative invisibility include the fact that extreme impacts are difficult to translate into monetary terms, they have a global scope, and they often require a time-horizon of a century or more. They cannot be understood simply by linear extrapolation of current trends, and they lack historical precedents.

There is also the fact that the measures required to significantly reduce the probability of infinite impacts will be radical compared to a business-as-usual scenario with a focus on incremental changes.

The exact probability of a specific impact is difficult or impossible to estimate.[8] However, the important thing is to establish the current magnitude of the probabilities and compare them with the probabilities for such impacts we cannot accept. A failure to provide any estimate for these riks often results in strategies and priorities defined as though the probability of a totally unacceptable outcome is zero. An approximate number for a best estimate also makes it easier to understand that a great uncertainty means the actual probability can be both much higher and much lower than the best estimate.

It should also be stressed that uncertainty is not a weakness in science; it always exists in scientific work. It is a systematic way of understanding the limitations of the methodology, data, etc.[9] Uncertainty is not a reason to wait to take action if the impacts are serious. Increased uncertainty is something that risk experts, e.g. insurance experts and security policy experts, interpret as a signal for action.

A contrasting challenge is that our cultural references to the threat of infinite impacts have been dominated throughout history by religious groups seeking to scare society without any scientific backing, often as a way to discipline people and implement unpopular measures. It should not have to be said, but this report is obviously fundamentally different as it focuses on scientific evidence from peer-reviewed sources.

Infinite impact

The concept infinite impact refers to two aspects in particular; the terminology is not meant to imply a literally infinite impact (with all the mathematical subtleties that would imply) but to serve as a reminder that these risks are of a different nature.

Ethical

These are impacts that threaten the very survival of humanity and life on Earth – and therefore can be seen as being infinitely negative from an ethical perspective. No positive gain can outweigh even a small probability for an infinite negative impact. Such risks require society to ensure that we eliminate these risks by reducing the impact below a infinite impact as a top priority, or at least do everything we can to reduce the probability of these risks. As some of these risks are impossible to eliminate today it is also important to discuss what probability can right now be accepted for risks with a possible infinite impact.

Economic

Infinite impacts are beyond what most traditional economic models today are able to cope with. The impacts are irreversible in the most fundamental way, so tools like cost-benefit assessment seldom make sense. To use discounting that makes infinite impacts, which could take place 100 years or more from now and affect all future generations, close to invisible in economic assessments, is another example of a challenge with current tools. So while tools like cost-benefit models and discounting can help us in some areas, they are seldom applicable in the context of infinite impacts. New tools are needed to guide the global economy in an age of potential infinite impacts.

See chapter 2.2.2 for a more detailed iscussion.

An additional challenge to acknowledging the risks in this report is that many of the traditional risks, including wars and violence, have decreased even though it might not always looks that way in media.[10] So a significant number of experts today spend a substantial amount of time trying to explain that much of what is discussed as dangerous trends might not be as dangerous as we think. For policy makers listening only to experts in traditional risk areas it is therefore easy to get the impression that global risks are becoming less of a problem.

The chain of events that could result in infinite impacts in this report also differ from most of the traditional risks, as most of them are not triggered by wilful acts, but accidents/mistakes. Even the probabilities related to nuclear war in this report are to a large degree related to inadvertent escalation. As many of the tools to analyse and address risks have been developed to protect nations and states from attacks, risks involving accidents tend to get less attention.

This report emphasises the need for an open and democratic process in addressing global challenges with potentially infinite impact. Hence, this is a scientifically based invitation to discuss how we as a global community can address what could be considered the greatest challenges of our time.

The difficulty for individual scientists to communicate a scientific risk approach should however not be underestimated. Scientists who today talk about low-probability impacts, that are serious but still far from infinite, are often accused of pessimism and scaremongering, even if they do nothing but highlight scientific findings.[11] To highlight infinite impacts with even lower probability can therefore be something that a scientist who care about his/her reputation want to avoid.

In the media it is still common to contrast the most probable climate impact with the probability that nothing, or almost nothing, will happen. The fact that almost nothing could happen is not wrong in most cases, but it is unscientific and dangerous if different levels of probability are presented as equal.

The tendency to compare the most probable climate impact with the possibility of a low or no impact also results in a situation where low-probability high-impact outcomes often are totally ignored. An honest and scientific approach is to, whenever possible, present the whole probability distribution and pay special attention to unacceptable outcomes.

The fact that we have challenges that with some probability might be infinite and therefore fundamentally irreversible is difficult to comprehend, and physiologically they are something our brains are poorly equipped to respond to, according to evolutionary psychologists.[12] It is hard for us as individuals to grasp that humanity for the first time in its history now has the capacity to create such catastrophic outcomes. Professor Marianne Frankenhaeuser, former head of the psychology division, Karolinska

Roulette and Russian roulette

When probability and normal risks are discussed the example of a casino and roulette is often used. You bet something, then spin the wheel and with a certain probability you win or lose. You can use different odds to discuss different kinds of risk taking. These kinds of thought experiment can be very useful, but when it comes to infinite risks these gaming analogies become problematic.

For infinite impact a more appropriate analogy is probably Russian roulette. But instead of “normal” Russian roulette where you only bet your own life you are now also betting everyone you know and everyone you don’t know. Everyone alive will die if you lose. There will be no second chance for anyone as there will be no future generations; humanity will end with your loss. What probability would you accept for different sums of money if you played this version of Russian roulette?

Most people would say that it is stupid and – no matter how low the probability is and no matter how big the potential win is – this kind of game should not be played, as it is unethical. Many would also say that no person should be allowed to make such a judgment, as those who are affected do not have a say. You could add that most of those who will lose from it cannot say anything as they are not born and will never exist if you lose.

The difference between ordinary roulette and “allhumanity Russian roulette” is one way of illustrating the difference in nature between a “normal” risk that is reversible, and a risk with an infinite impact.

Institute, Stockholm, put it this way: "Part of the answer is to be found in psychological defence mechanisms. The nuclear threat is collectively denied, because to face it would force us to face some aspects of the world's situation which we do not want to recognise." [13]

This psychological denial may be one reason why there is a tendency among some stakeholders to confuse "being optimistic" with denying what science is telling us, and ignoring parts of the probability curve.[14] Ignoring the fact that there is strong scientific evidence for serious impacts in different areas, and focusing only on selected sources which suggest that the problem may not be so serious, is not optimistic. It is both unscientific and dangerous.[15]

A scientific approach requires us to base our decisions on the whole probability distribution. Whether it is possible to address the challenge or not is the area where optimism and pessimism can make people look at the same set of data and come to different conclusions.

Two things are important to keep in mind: first, that there is always a probability distribution when it comes to risk; second, that there are two different kinds of impacts that are of interest for this report. The probability distribution can have different shapes but in simplified cases the shape tends to look like a slightly modified clock (remember figure X).

In the media it can sound as though experts argue whether an impact, for example a climate impact or a pandemic, will be dangerous or not. But what serious experts discuss is the probability of different oucomes. They can disagree on the shape of the curve or what curves should be studied, but not that a probability curve exist. With climate change this includes discussions about how how sensitive the climate is, how much greenhouse gas will be emitted, and what impacts that different warmings will result in.

Just as it is important not to ignore challenges with potentially infinite impacts, it is also important not to use them to scare people. Dramatic images and strong language are best avoided whenever possible, as this group of risks require sophisticated strategies that benefit from rational arguments. Throughout history we have seen too many examples when threats of danger have been damagingly used to undermine important values.

The history of infinite impacts: The LA-602 document

The understanding of infinite impacts is very recent compared with most of our institutions and laws. It is only 70 years ago that Edward Teller, one of the greatest physicists of his time, with his back-of-the-envelope calculations, produced results that differed drastically from all that had gone before. His calculations indicated that the explosion of a nuclear bomb – a creation of some of the brightest minds on the planet, including Teller himself – could result in a chain reaction so powerful that it would ignite the world's atmosphere, thereby ending human life on Earth.[16]

Robert Oppenheimer, who led the Manhattan Project to develop the nuclear bomb, halted the project to see whether Teller's calculations were correct.[17] The resulting document, LA-602: Ignition of the Atmosphere with Nuclear Bombs, concluded that Teller was wrong, But the sheer complexity drove them to end their assessment by writing that "further work on the subject [is] highly desirable".[18]

The LA-602 document can be seen as the first scientific global risk report addressing a category of risks where the worst possible impact in all practical senses is infinite.[19] Since the atomic bomb more challenges have emerged with potential infinite impact. Allmost all of these new challenges are linked to the increased knowledge, economic and technical development that has brought so many benefits. For example, climate change is the result of the industrial revolution and development that was, and still is, based heavily on fossil fuel.

The increased potential for global pandemics is the result of an integrated global economy where goods and services move quickly around the world, combined with rapid urbanisation and high population density.

In parallel with the increased number of risks with possible infinite impact, our capacity to analyse and solve them has greatly increased too. Science and technology today provide us with knowledge and tools that can radically reduce the risks that historically have been behind major extinctions, such as pandemics and asteroids.

Recent challenges like climate change, and emerging challenges like synthetic biology and nanotechnology, can to a large degree be addressed by smart use of new technologies, new lifestyles and institutional structures. It will be hard as it will require collaboration of a kind that we have not seen before. It will also require us to create systems that can deal with the problems before they occur. The fact that the same knowledge and tools can be both a problem and a solution is important to understand to avoid polarisation.

Within a few decades, or even sooner, many of the tools that can help us solve the global challenges of today will come from fields likely to provide us with the most powerful instruments we have ever had – resulting in their own sets of challenges.

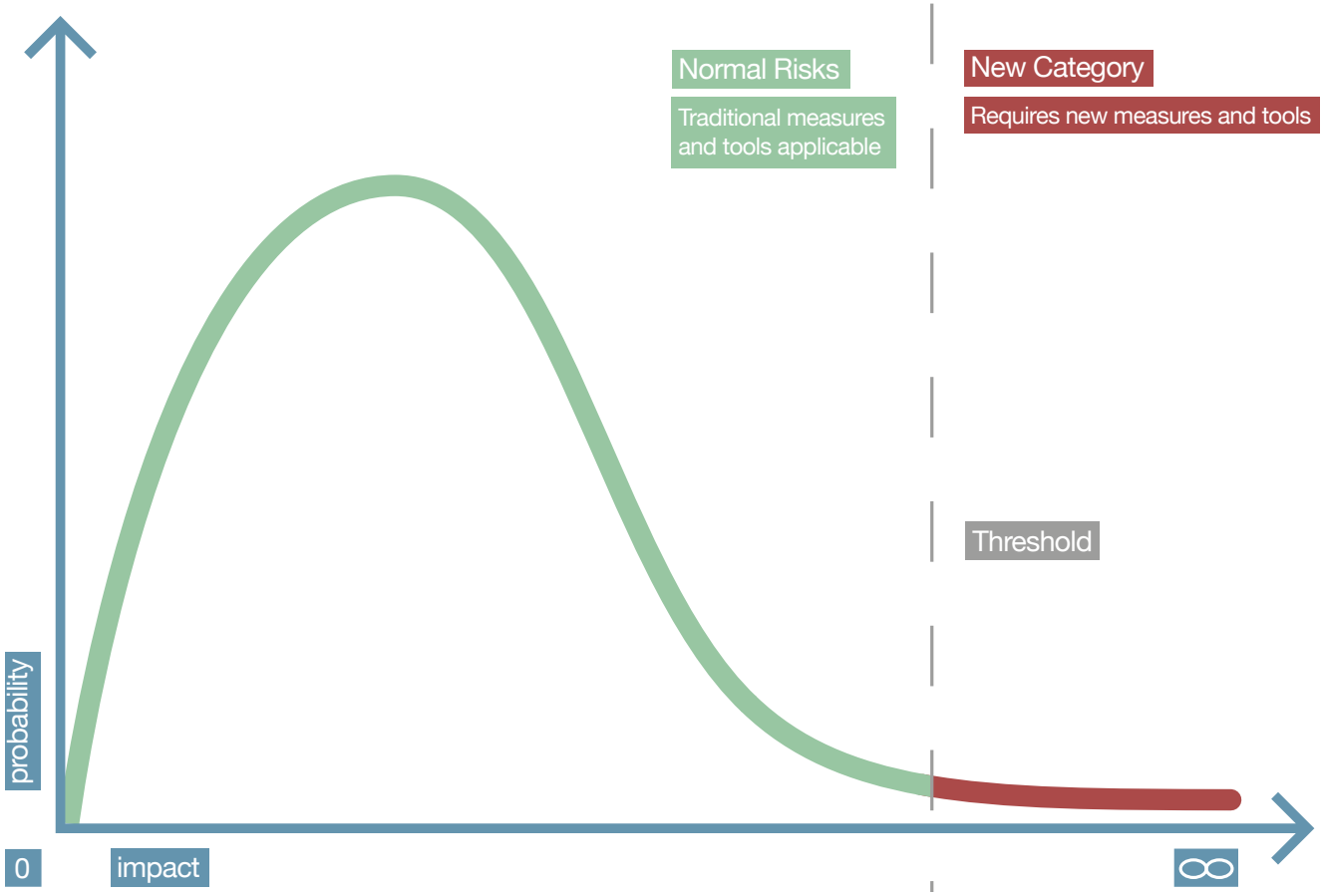
Synthetic biology, nanotechnology and artificial intelligence (AI) are all rapidly evolving fields with great potential to help solve many of today's main challenges as well as resulting in infinite impact if not guided in a benign direction.

The point of departure of this report is the fact that we now have the knowledge, economic resources and technological ability to reduce most of the greatest risks of our time.

Conversely, the infinite impacts we face are almost all unintended results of human ingenuity. The reason we are in this situation is that we have made progress in many areas without addressing unintended low-probability high-impact consequences.

Creating innovative and resilient systems rather than simply managing risk would let us focus more on opportunities. But the resilience needed require moving away from legacy systems and is likely to be disruptive, so an open and transparent discussion is needed regarding the transformative solutions required.

Figure 3: Probability density function with tail and threshold highlighted



2.1 Report structure

The first part of the report is an introduction where the global risks with potential infinite impact are introduced and defined. This part also includes the methodology for selecting these risks, and presents the twelve risks that meet this definition. Four goals of the report are also presented, under the headings “acknowledge”, “inspire”, “connect” and “deliver”.

The second part is an overview of the twelve global risks and key events that illustrate some of the work around the world to address them. For each challenge five important factors that influence the probability or impact are also listed.

The risks are divided into four different categories depending on their characteristics.

“Current challenges” is the first category and includes the risks that currently threaten humanity due to our economic and technological development - extreme climate change, for example, which depends on how much greenhouse gas we emit.

“Exogenic challenges” includes risks where the basic probability of an event is beyond human control, but where the probability and magnitude of the impact can be influenced - asteroid impacts, for example, where the asteroids’ paths are beyond human control but an impact can be moderated by either changing the direction of the asteroid or preparing for an impact.

“Emerging challenges” includes areas where technological development and scientific assessment indicate that they could both be a very important contribution to human welfare and help reduce the risks associated with current challenges, but could also result in new infinite impacts.[20] AI, nanotechnology and synthetic biology are examples.

“Global policy challenge” is a different kind of risk. It is a probable threat arising from future global governance as it resorts to destructive policies, possibly in response to the other challenges listed above.

The third part of the report discusses the relationship between the different risks. Action to reduce one risk can increase another, unless their possible links are understood. Many solutions are also able to address multiple risks, so there are significant benefits from understanding how one relates to others. Investigating these correlations could be a start, but correlation is a linear measure and non-linear techniques may be more helpful for assessing the aggregate risk.

The fourth part is an overview, the first ever to our knowledge, of the uncertainties and probabilities of global risks with potential infinite impacts. The numbers are only rough estimated and meant to be a first step in a dialogue where methodologies are developed and estimates refined.

The fifth part presents some of the most important underlying trends that influence the global challenges, which often build up slowly until they reach a threshold and very rapid changes ensue.

The sixth and final part presents an overview of possible ways forward.

2.2 Goals

Establish a category of risks with possible infinite impact

Before anything significant can happen regarding global risks with possible infinite impacts, their existence must be acknowledged.

Rapid technological development and economic growth have delivered unprecedented material welfare to billions of people in a veritable tide of utopias.[21]

But we now face the possibility that even tools created with the best of intentions can have a darker side too, a side that may threaten human civilisation, and conceivably the continuation of human life.

This is what all decision-makers need to recognise. Rather than succumbing to terror, though, we need to acknowledge that we can let the prospect inspire and drive us forward.

Goal 1: Acknowledge

That key stakeholders, influencing global challenges, acknowledge the existence of the category of risks that could result ininfinite impact. They should also recognice that the list of risks that belong to this category should be revised as new technologies are developed and our knowledge increases. Regardless of the risks included, the category should be given special attention in all processes and decisions of relevance. The report also seeks to demonstrate to all key stakeholders that we have the capacity to reduce, or even eliminate, most of the risks in this category.

Show concrete action that is taking place today

This report seeks to show that it is not only possible to contribute to reducing these risks, but that it is perhaps the most important thing anyone can spend their time on.

It does so by combining information about the risks with information about individuals and groups who has made a significant contribution by turning challenges into opportunities.

By highlighting concrete examples the report hopes to inspire a new generation of leaders.

Goal 2: Inspire

That policy makers inspire action by explaining how the probabilities and impacts can be reduced and turned into opportunities. Concrete examples of initiatives should be communicated in different networks in order to create ripple effects, with the long-term goal that all key stakeholders should be inspired to turn these risks into opportunities for positive action.

Support new meetings between interested stakeholders

The nature of these risks spans countries and continents; they require action by governments and politicians, but also by companies, academia, NGOs, and many other groups. The magnitude of the possible impacts requires not only leaders to act but above all new models for global cooperation and decision-making to ensure delivery. The need for political leadership is therefore crucial.

Even with those risks where many groups are involved, such as climate change and pandemics, very few today address the possibility of infinite impact aspects.

Even fewer groups address the links between the different risks.

There is also a need to connect different levels of work, so that local, regional, national and international efforts can support each other when it comes to risks with potential infinite impacts.

Goal 3: Connect

That leaders in different sectors connect with each other to encourage collaboration. A specific focus on financial and security policy where significant risks combine to demand action beyond the incremental is required.

Identify and implement strategies and initiatives

Reports can acknowledge, inspire and connect, but only people can deliver actual results. The main focus of the report is to show that actual initiatives need to be taken that deliver actual results.

Only when the probability of an infinite impact becomes acceptably low, very close to zero, and/or when the maximum impact is significantly reduced, should we talk about real progress.

In order to deliver results it is important to remember that global governance to tackle these risks is the way we organise society in order to address our greatest challenges. It is not a question of establishing a “world government”, it is about the way we organise ourselves on all levels, from the local to the global.

The report is a first step and should be seen as an invitation to all responsible parties that can affect the probability and impact of risks with potentially infinite impacts. But its success will ultimately be measured only on how it contributes to concrete results.

Goal 4: Deliver

That concrete strategies are developed that allow key stakeholders to identify, quantify and address global challenges as well as gather support for concrete steps towards a well-functioning global governance system, This would include tools and initiatives that can help identify, quantify and reduce risks with possible Infinite impacts.

2.3 Global challenges and infinite impact

This chapter first introduces the concept of infinite impact. It then describes the methodology used to identify challenges with an infinite impact. It then presents risks with potentially infinite impact that the methodology results in.

2.3.1 Definition of infinite impact

The specific criterion for including a risk in this report is that well-sourced science shows the challenge can have the following consequences: [22]

1. Infinite impact: When civilisation collapses to a state of great suffering and do not recover, or a situation where all human life end. The existence of such threats is well attested by science.[23]
2. Infinite impact threshold – an impact that can trigger a chain of events that could result first in a civilisation collapse, and then later result in an infinite impact. Such thresholds are especially important to recognise in a complex and interconnected society where resilience is decreeing.[24]

A collapse of civilisation is defined as a drastic decrease in human population size and political/ economic/social complexity, globally for an extended time.[25] The above definition means the list of challenges is not static. When new challenges emerge, or current ones fade away, the list will change.

An additional criterion for including risks in this report is "human influence". Only risks where humans can influence either the probability, the impact, or both, are included. For most risks both impact and probability can be affected, for example with nuclear war, where the number/size of weapons influences the impact and tensions between countries affect the probability.

Other risks, such as a supervolcano, are included as it is possible to affect the impact through various mitigation methods, even if we currently cannot affect the probability. Risks that are susceptible to human influence are indirectly linked, because efforts to address one of them may increase or decrease the likelihood of another.

2.3.2 Why use "infinite impact" as a concept?

The concept of infinity was chosen as it reflects many of the challenges, especially in economic theory, to addressing these risks as well as the need to question much of our current way of thinking.

The concept of a category of risks based on their extreme impact is meant to provide a tool to distinguish one particular kind of risk from others. The benefit of this new concept should be assessed based on two things. First, does the category exist, and second, is the concept helpful in addressing these risks?

The report has found ample evidence that there are risks with an impact that can end human civilisation and even all human life. The report further concludes that a new category of risk is not only meaningful but also timely. We live in a society where global risks with potentially infinite impacts increase in numbers and probability according to a number of studies. Looking ahead many emerging technologies, which will certainly provide beneficial results, can result in an increased probability of infinite impacts.[26]

Over the last few years a greater understanding of low probability or unknown probability has helped more people to understand the importance of looking beyond the most probable scenarios. Concepts like "black swans" and "perfect storms" are now part of mainstream policy and business language.[27]

Greater understanding of the technology and science of complex systems has also resulted in a new understanding of potentially disruptive events. Humans now have such an impact on the planet that the term "the anthropocene" is being used, even by mainstream media like The Economist.[28] The term was introduced in the 90s by the Nobel Prize winner Paul Crutzen to describe how humans are now the dominant force changing the Earth's ecosystems.[29]

The idea to establish a well category of risks that focus on risks with a possible infinite impact that can be used as a practical tool by policy makers is partly inspired by Nick Bostrom's philosophical work and his introduction of a risk taxonomy that includes an academic category called "existential risks".[30]

Introducing a category with risks that have a potentially infinite impact is not meant to be a mathematical definition; infinity is a thorny mathematical concept and nothing in reality can be infinite.[31] It is meant to illustrate a singularity, when humanity is threatened, when many of the tools used to approach most challenges today become problematic, meaningless, or even counterproductive.

The concept of an infinite impact highlights a unique situation where humanity itself is threatened and the very idea of value and price collapses from a human perspective, as the

price of the last humans also can be seen to be infinite. This is not to say that those traditional tools cannot still be useful, but with infinite impacts we need to add an additional set of analytical tools.

Some of the risks, including nuclear war, climate change and pandemics, are often included in current risk overviews, but in many cases their possible infinite impacts are excluded. The impacts which are included are in most cases still very serious, but only the more probable parts of the probability distributions are included, and the last part of the long tail – where the infinite impact is found - is excluded.[32]

Most risk reports do not differentiate between challenges with a limited impact and those with a potential infinite impact. This is dangerous, as it can mean resources are spent in ways that increase the probability of an infinite impact.

Ethical aspects of infinite impact

The basic ethical aspect of infinite impact is this: a very small group alive today can take decisions that will fundamentally affect all future generations.

"All future generations" is not a concept that is often discussed, and for good reason. All through human history we have had no tools with a measurable global impact for more than a few generations. Only in the last few decades has our potential impact reached a level where all future generations can be affected, for the simple reason that we now have the technological capacity to end human civilisation.

If we count human history from the time when we began to practice settled agriculture, that gives us about 12,000 years.[33] If we make a moderate assumption that humanity will live for at least 50 million more years[34] our 12,000-year history so far represents 1/4200, or 0.024%, of our potential history. So our generation has the option of risking everything and annulling 99.976% of our potential history. Comparing 0.024% with the days of a person living to 100 years from the day of conception, this would equal less than nine days and is the first stage of human embryogenesis, the germinal stage.[35] Two additional arguments to treat potentially infinite impacts as a separate category are: [36]

1. An approach to infinite impacts cannot be one of trial-and-error, because there is no opportunity to learn from errors. The reactive approach – see what happens, limit damage, and learn from experience – is unworkable. Instead society must be proactive. This requires foresight to foresee new types of threat and willingness to take decisive preventative action and to bear the costs (moral and economic) of such actions.

Life Value

The following estimates have been applied to the value of life in the US. The estimates are either for one year of additional life or for the statistical value of a single life.

– $50,000 per year of quality life (international standard most private and government-run health insurance plans worldwide use to determine whether to cover a new medical procedure)

– $129,000 per year of quality life (based on analysis of kidney dialysis procedures by Stefanos Zenios and colleagues at Stanford Graduate School of Business)

– $7.4 million (Environmental Protection Agency)

– $7.9 million (Food and Drug Administration)

– $6 million (Transportation Department)

– $28 million (Richard Posner based on the willingness to pay for avoiding a plane crash)

Source: Wikipedia: Value of life http://en.wikipedia.org/wiki/Value_of_life
US EPA: Frequently Asked Questions on Mortality Risk Valuation

http://yosemite.epa.gov/EE%5Cepa%5Ceed.nsf/webpages/MortalityRiskValuation.html

Posner, Richard A. Catastrophe: risk and response. Oxford University Press, 2004

2. We cannot necessarily rely on the institutions, morality, social attitudes or national security policies that developed from our experience of other sorts of risk. Infinite impacts are in a different category. Institutions and individuals may find it hard to take these risks seriously simply because they lie outside our experience. Our collective fear-response will probably be ill-calibrated to the magnitude of threat.

Economic aspects of infinite impact and discounting

In today's society a monetary value is sometimes ascribed to human life. Some experts use this method to estimate risk by assigning a monetary value to human extinction.[37]

We have to remember that the monetary values placed on a human life in most cases are not meant to suggest that we have actually assigned a specific value to a life. Assigning a value to a human life is a tool used in a society with a limited supply of resources or infrastructure (ambulances, perhaps) or skills. In such a society it is impossible to save every life, so some trade-off must be made.[38] The US Environmental Protection Agency explains its use like this: "The EPA does not place a dollar value on individual lives. Rather, when conducting a benefit-cost analysis of new environmental policies, the Agency uses estimates of how much people are willing to pay for small reductions in their risks of dying from adverse health conditions that may be caused by environmental pollution." [39]

The fact that monetary values for human lives can help to define priorities when it comes to smaller risks does not mean that they are suitable for quite different uses. Applying a monetary value to the whole human race makes little sense to most people, and from an economic perspective it makes no sense. Money helps us to prioritise, but with no humans there would be no economy and no need for priorities.

Ignoring, or discounting, future generations is actually the only way to avoid astronomical numbers for impacts that may seriously affect every generation to come. In Catastrophe: Risk and Response, Richard Posner provides a cost estimate, based on the assumption that a human life is worth $50,000, resulting in a $300 tn cost for the whole of humanity, assuming a population of six billion. He then doubles the population number to include the value of all future generations, ending up with $600 tn, while acknowledging that "without discounting, the present value of the benefits of risk-avoidance measures would often approach infinity for the type of catastrophic risk with which this book is concerned." [40]

Discounting for risks that include the possibility of an infinite impact differs from risk discounting for less serious impacts. For example the Stern Review[41] prompted a discussion between its chief author, Nicholas Stern, and William Nordhaus,[42] each of whom argued for different discount levels using different arguments. But neither discussed a possible infinite climate impact. An overview of the discussion by David Evans of Oxford Brookes University highlighted some of the differing assumptions.[43]

Two things make infinite impacts special from a discounting perspective. First, there is no way that future generations can compensate for the impact, as they will not exist. Second, the impact is something that is beyond an individual preference, as society will no longer exist.

Discounting is undertaken to allocate resources in the most productive way. In cases that do not include infinite impacts, discounting "reflects the fact that there are many high-yield investments that would improve the quality of life for future generations. The discount rate should be set so that our investable funds are devoted to the most productive uses." [44] When there is a potential infinite impact the focus is no longer on what investments have the best rate of return, it is about avoiding the ultimate end.

While many economists shy away from infinite impacts those exploring the potential extreme impacts of global challenges often assume infinite numbers to make their point. Nordhaus for example writes that "the sum of undiscounted anxieties would be infinite (i.e. equal to 1 + 1 +1 + … = ∞). In this situation, most of us would dissolve in a sea of anxiety about all the things that could go wrong for distant generations from asteroids, wars, out-of-control robots, fat tails, smart dust and other disasters." [45]

It is interesting that Nordhaus himself provides very good graphs that show why the most important factor when determining actions is a possible threshold (see below Figure X and X+1). Nordhaus was discussing climate change, but the role of thresholds is similar for most infinite impacts. The first figure is based on traditional economic approaches which assume that Nature has no thresholds; the second graph illustrates what happens with the curve when a threshold exists. As Nordhaus also notes, it is hard to establish thresholds, but if they are significant all other assumptions become secondary. The challenge that Nordhaus does not address, and which is important especially with climate change, is that thresholds become invisible in economic calculations if they occur far into the future, even if it is current actions that

unbalance the system and eventually push it over the threshold.[46]

Note that these dramatic illustrations rest on assumptions that the thresholds are still relatively benign, not moving us beyond tipping points which result in an accelerated release of methane that could result in a temperature increase of more than 8 °C, possibly producing infinite impacts.[47]

Calculating illustrative numbers

By including the welfare of future generations, something that is important when their very existence is threatened, economic discounting becomes difficult. In this chapter some illustrative numbers are provided to indicate the order of magnitude of the values that calculations provide when traditional calculations also include future generations. These illustrative calculations are only illustrative as the timespans that must be used make all traditional assumptions questionable to say the least. Still as an indicator for why infinite impact might be a good approximation they might help.

As a spieces that can manipulate our environment it could be argued that the time the human race will be around, if we do not kill ourselves, can be estimated to be between 1-10 million years – the typical time period for the biological evolution of a successful species[48] – and one billion years, the inhabitable time of Earth.[49]

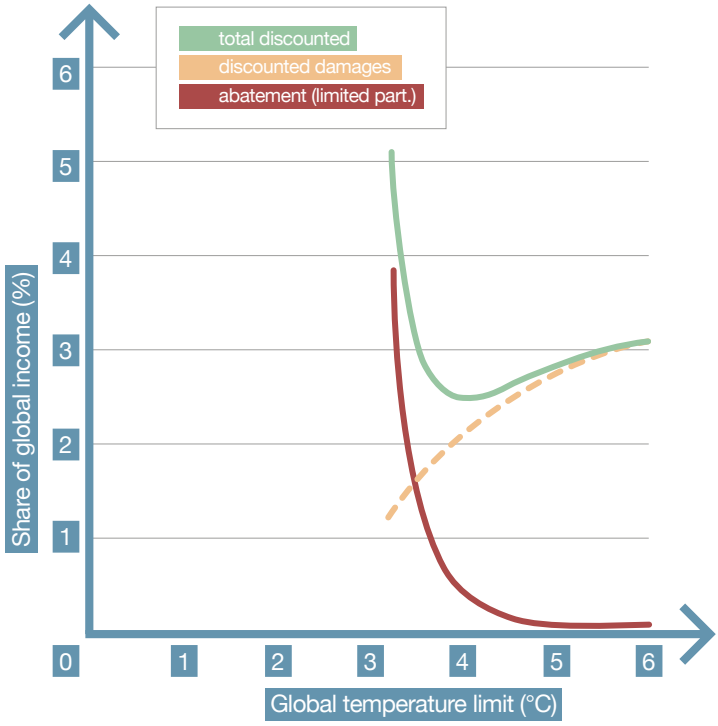


Figure 4: *Nordhaus, The Climate Casino*: Total cost of different targets assuming limited participation and discounting of future incomes.

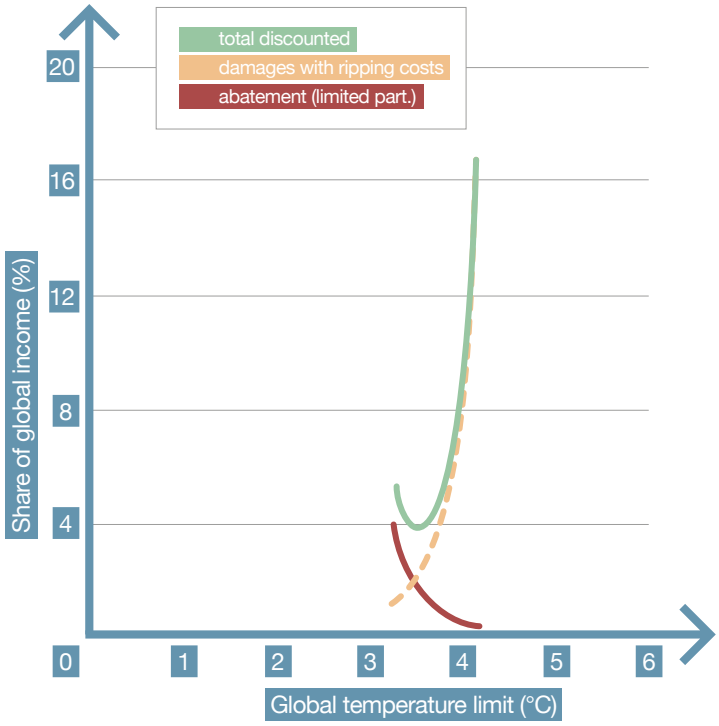


Figure 5: *Nordhaus, The Climate Casino*: Climate policy with a sharp tipping point at 3.5°C. This shows that the optimal temperature increase is very close to the threshold. It is constrained on the low side by abatement costs and on the high side by the sharp increase in damages

If we assume

– 50 million years for the future of humanity as our reference,
– an average life expectancy of 100 years[50], and
– a global population of 6 billion people[51]
– all conservative estimate – , we have half a million generations ahead of us with a total of 3 quadrillion individuals.

Assuming a value of $50,000 per life, the cost of losing them would then be $1.5 ×1020, or $150 quintillion.

This is a very low estimate and Posner suggests that maybe the cost of a life should be "written up $28 million" for catastrophic risks[52]. Posner's calculations, where only one future generation is included, result in a cost of $336 quadrillion. If we include all future generations with the same value, $28 million, the result is a total cost of $86 sextillion, or $86 × 1021.

This $86 sextillion is obviously a very rough number (using one billion years instead of 50 million would for example require us to multiply the results by 20), but again it is the magnitude that is interesting. As a reference there are about 1011 to 1012 stars in our galaxy, and perhaps something like the same number of galaxies. With this simple calculation you get 1022 to 1024, or 10 to 1,000 sextillion, stars in the universe to put the cost of infinite impacts when including future generations in perspective.[53]

These numbers can be multiplied many times if a more philosophical and technology-optimistic scenario is assumed for how many lives we should include in future generations. The following quote is from an article by Nick Bostrom in Global Policy Journal:

> *"However, the relevant figure is not how many people could live on Earth but how many descendants we could have in total. One lower bound of the number of biological human life-years in the future accessible universe (based on current cosmological estimates) is 1034 years. Another estimate, which assumes that future minds will be mainly implemented in computational hardware instead of biological neuronal wetware, produces a lower bound of 1054 human-brain-emulation subjective life-years."* [54]

Likewise the value of a life, $28 million, a value that is based on an assessment of how individual chose when it comes to flying, can be seen a much to small. This value is based on how much we value our own lives on the margin, it is reasonable to assume that the value would be higher than only a multiplication of our own value if we also considered the risk of loosing our family, everyone we know, as well as everyone on the planet. In the same way as the cost increase when a certain product is in short supply, the cost of the last humans could be assumed to be very high, if not infinite.

Obviously, the very idea to put a price on the survival of humanity can be questioned for good reasons, but if we still want to use a number the $28 million per life should at least be considered as a significant underestimation.

For those that are reluctant or unable to use infinity in calculations and are in need of a number for their formulas, $86 sextillion could be a good initial start for the cost of infinite impacts. But it is important to note that this number might be orders of magnitude smaller than an estimate which actually took into account a more correct estimation of the number of people that should be included in future generations as well as the price that should be assigned to the loss of the last humans.

2.3.3 Infinite impact threshold (IIT)

As we address very complex systems, such as human civilisation and global ecosystems, a concept as important as infinite impact in this report is that of infinity impact threshold. This is the impact level that can trigger a chain of events that results in the end of human civilisation.

The infinite impact threshold (IIT) concept represents the idea that long before an actual infinite impact is reached there is a tipping point where it, with some probability, is no longer possible to reverse events. So instead of focusing only on the ultimate impact it is important to estimate what level of impact the infinity threshold entails.

The IIT is defined as an impact that can trigger a chain of events that could result first in a civilisation collapse, and then later result in an infinite impact. Such thresholds are especially important to recognise in a complex and interconnected society where resilience is decreeing.

Social and ecological systems are complex, and in most complex systems there are thresholds where positive feedback loops become self-reinforcing. In a system where resilience is too low, feedback loops can result in a total system collapse. These thresholds are very difficult to estimate and in most cases it is possible only to estimate their order of magnitude.

As David Orrell and Patrick McSharry wrote in A systems approach to forecasting: "Complex systems have emergent properties, qualities that cannot be predicted in advance from knowledge of systems components alone". According to complexity scientist Stephen Wolfram's principle of computational irreducibility, the only way to predict the evolution of such a system is to run the system itself: "There is no simple set of equations that can look into its future." [55]

Orrell and McSharry also noted that "in orthodox economics, the reductionist approach means that the economy is seen as consisting of individual, independent agents who act to maximise their own utility. It assumes that prices are driven to a state of near-equilibrium by the 'invisible hand' of the economy. Deviations from this state are assumed to be random and independent, so the price fluctuations are often modelled using the normal distribution or other distributions with thin tails and finite variance."

The drawbacks of an approach using the normal distribution, or other distributions with thin tails and finite variance, become obvious when the unexpected happens as in the recent credit crunch, when existing models totally failed to capture the true risks of the economy. As an employee of Lehman Brothers put it on August 11, 2007: 'Events tha models predicted would happen only once in 10,000 years happened every day for three days.'" [56]

Figure 6: Normal risks and risks with possible infinite impact

The exact level for an infinite impact threshold should not be the focus, but rather the fact that such thresholds exists and that an order of magnitude should be estimated.[57] During the process of the project to write the report experts suggested that a relatively quick death of two billion people could be used as a tentative number until more research is available.[58] With current trends undermining ecological and social resilience it should be noted that the threshold level is likely to become lower as time progress.

2.3.4 Global F-N curves and ALARP

In the context of global risks with potentially infinite impact the possibility to establish global F-N curves is worth exploring. One of the most common and flexible frameworks used for risk criteria divides risks into three bands: [59]

1. Upper: an unacceptable/ intolerable region, where risks are intolerable except in extraordinary circumstances and risk reduction measures are essential.
2. Middle: an ALARP ("as low as reasonably practicable") region, where risk reduction measures are desirable but may not be implemented if their cost is disproportionate to the benefit achieved.
3. Lower: a broadly acceptable/ negligible region, where no further risk reduction measures are needed.

The bands are expressed by F-N curves. When the frequency of events which cause at least N fatalities is plotted against the number N on log log scales, the result is called an F-N curve.[60] If the frequency scale is replaced by annual probability, then the resultant curve is called an f-N curve.

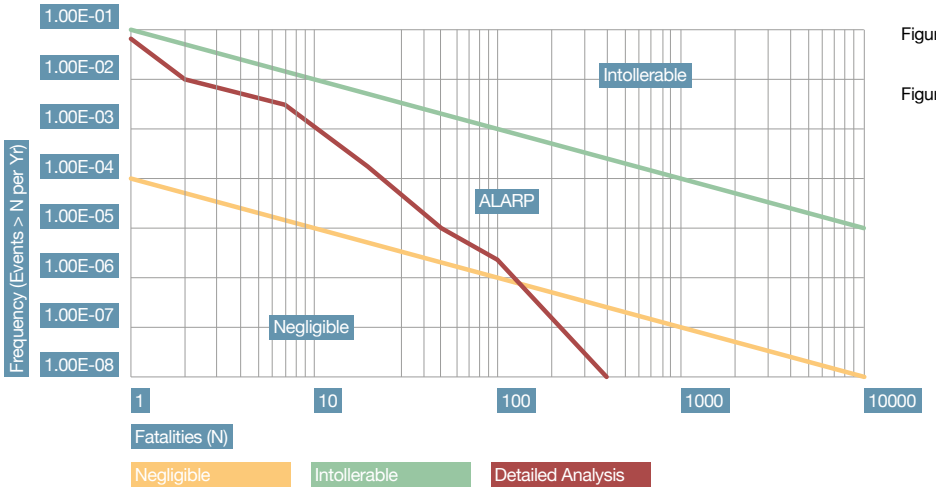


Figure 7: Example of F-n Curve Showing Different Levels of Risk [61]

Figure 8: Example of F-n Curve Showing an absolute impact level that is defined as unacceptable/ infinite. i.e no level of probability is acceptable above a certain level of impact, in this case 1000 dead [64]

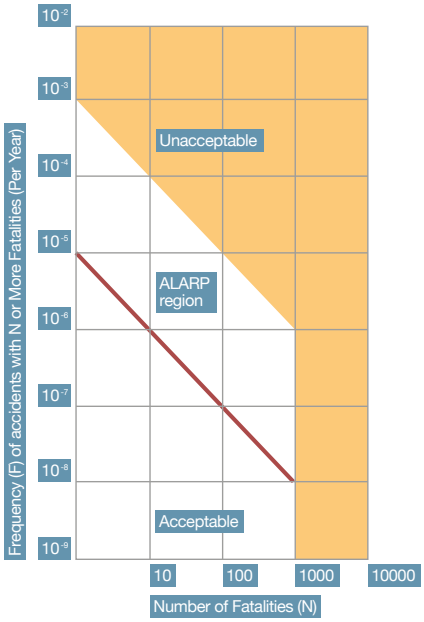
The concept for the middle band when using F-N curves is ALARP. It is a term often used in the area of safety-critical and safety-involved systems.[62] The ALARP principle is that the residual risk should be as low as reasonably practicable.

The upper band, the unacceptable/ intolerable region, is usually the area above the ALARP area (see figure Z1) Figure X: Pros and cons of F-N curves.

By using F-N curves it is also possible to establish absolute impact levels that are never acceptable, regardless of probability (Figure Z2. Based on an actual F-n Curve showing an absolute impact level that is defined as unacceptable). This has been done in some cases for local projects. The infinite threshold could be used to create an impact limit on global F-N curves used for global challenges in the future. Such an approach would help governments, companies and researchers when they develop new technical solutions and when investing in resilience. Instead of reducing risk, such an approach encourages the building of systems which cannot have negative impacts above a certain level.

Pros	Cons
– Clearly shows relationship between frequency and size of accident	– Cumulative expression makes it difficult to interpret, especially by non-risk specialists
– Allows judgement on relative importance of different sizes of accident	– Can be awkard to derive
– Slope steeper than -1 provides explicit consideration of multiple fatality aversion and favours concepts with lower potential for large fatality events	– May be difficult to use if criterion is exceeded in one area but otherwise is well below
– Allows company to manage overall risk exposure from portfolio of all existing and future facilities	– Much debate about criterion lines

Figure 9: Pros and cons of F-N curves [63]



2.3.5 A name for a clearly defined group of risks that can provide practical guidance

Today no established methodology exists that provides a constantly updated list of risks that threaten human civilisation, or even all human life. Given that such a category can help society to better understand and act to avoid such risks, and better understand the relation between these risks, it can be argued that a name for this category would be helpful.[65]

To name something that refer to end of humanity is in itself a challenge as the very idea is so far from our usual references and to many the intuitive feeling will be to dismiss any such thing.

The concept used in this report is “infinity”. The reson for this is that many of the challenges relate to macroeconomics and its challenges in relation to the kind of impacts that the risks in this report focus on.

To illustrate the fact that an impact that can not be acceptable in anyway inifinity highlights the fact that this is beyond the scope of most cost benefit modelts.

Further, the name clearly highlights the unique nature without any normative judgements.

Still, infinity is an abstract concept and it might not be best communicate the unique group of risks that it covers to all stakeholders. In the same way as it can be hard to use a singularity to describe a black hole, it can be difficult to use infinity to describe a certain risk. If people can accept that it is only from a specific perspective that the infinity concept is relevant it could be used beyond the areas of macroeconomics.

Two other concepts that also have been considered during the process of writing this report are “xrisks” and “human risk of ruin”. Xrisk has the advantage, and disadvantage, of not really saying anything at all about the risk. The positive aspect is that the name can be associated with the general concept of extinction and the philosophical concept of existential risk as both have the letter x in them. The disadvantage is the x often represents the unkown and can therefore relate to any risk. There is nothing in the name that directly relate to the kind of impacts that the category covers, so it is easy to interpret the term as just unknown risks.

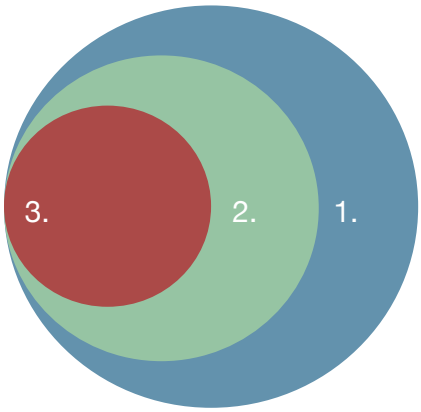
Human risk of ruin has the adventage of having a direct link to a concept, risk of ruin, that relate to a very specific state where all is lost. As risk of ruin is a consept use in gambling, insurance, and finance that all can give very important contributions to the work with this new category of risk. The resemblense to an existing consept that is well established could both be a strength and a liability.

Below is an overview of the process when different names were discussed. In one way the name is not very important as long as people understand the impacts and risks associated with it. Still, a name is symbolic and can either help or make it more difficult to get support to establish the new category.

The work to establish a list of risks with infinite impact evolved from “existential risk”, the philosophical concept that inspired much of the work to establish a clearly defined group of risks. The reason for not using the concept “existential risk and impact” for this category, beside the fact that existential impact is also used in academic contexts to refer to a personal impact, is that the infinite category is a smaller subset of “existential risk” and this new category ment to be used as a tool, not a scientific concept. Not only should the impacts in the category potentially result in the end of all human life, it should be possible to affect the probability and/or impact of that risk. It must also exist an agreed methodology, such as the one suggested in this report, that decides what risks belong and not belong on the list.

Another concept that the category relates to is “global catastrophic risk” as it is one of the most used concepts among academics interested in infinite impacts. However it is vague enough to be used to refer to impacts from a few thousand deaths to the end of human civilisation. Already in use but not clearly defined, it includes both the academic concept existential risks and the category of risks with infinite impacts.

The three concepts are very different. Global catastrophic risk is possibly the most used concept in contexts where infinite impacts are included, but it is without any clear definition. Existential risk is an academic concept used by a much smaller group and with particular focus on future technologies. The category in this report is a tool to help decision makers develop strategies that help reduce the probability that humanity will end when it can be avoided. The relation between the three concepts can be illustrated with three circles. The large circle (1) represents global catastrophic risks, the middle one (2) existential risks and the small circle (3) The list of twelve risks in this report, i.e. risks where there are peer reviewed academic studies that estimate the probability for an infinite impact and where there are known ways to reduce the risk. A list that could be called infinite risks, xrisks, or human risk of ruin.



Other concepts that are related to infinite impacts that could potentially be used to describe the same category if the above suggestions are not seen as acceptable concepts are presented below, together with the main reason why these concepts were not chosen for this report.

1. Risk of ruin – is a concept in gambling, insurance and finance relating to the likelihood of losing all one's capital or affecting one's bankroll beyond the point of recovery. It is used to describe individual companies rather than systems.[66]
2. Extinction risk – is used in biology for any species that is threatened. The concept is also used in memory/cognition research. It is a very dramatic term, to be used with care. These factors make it probably unsuitable for use by stakeholders accustomed to traditional risk assessment.
3. Astronomical risk – is seldom used scientifically, but when it is used it is often used for asteroids and is probably best reserved for them.[67]
4. Apocalyptic risk – could have been suitable, as the original meaning is apocálypsis, from the Greek ἀπό and καλύπτω meaning 'un-covering'. It is sometime used, but in a more general sense, to significant risks.[68] But through history and today it is mainly used for a religious end of time scenario. Its strong links to unscientific doom-mongers make it probably unsuitable for a scientific concept.
5. End-of-the-world risk - belongs to the irrational doomsday narrative and so is probably unsuitable for scientific risk assessments
6. Extreme risk – is vague enough to describe anything beyond the normal, so it is probably unsuitable for risk assessments.
7. Unique risk – is even vaguer, as every risk is unique in some way. Probably best avoided in risk assessments.
8. Collapse risk – is based on Jared Diamond's thinking.[69] There are many different kinds of collapse and only a few result in infinite impact.
9. Unacceptable risks in different combinations, e.g. unacceptable global risks – This is probably not appropriate for two main reasons. First, it is a normative statement and the category aims to be scientific; whether these risks are unacceptable or not is up to the citizens of the world to decide. Second, the idea of risk is that it is a combination of probability times impact. If a risk is unacceptable is therefore also usually related to how easy it is to avoid. Even if a risk is small, due to relatively low probability and relatively low impact, but is very easy to address, it can be seen as unacceptable. In the same way a large risk can be seen as acceptable if it would require significant resources to reduce.

There will not be a perfect concept and the question is what concept can find the best balance between being easy to understand, acceptable where policy decisions needs to be made and also acceptable for all key groups that are relevant for work in these area. During the process to find a name for this category inspiration has been found in the process when new concepts has been introduces from irrational numbers and genocide to sustainable development and Human Development Index. So far "infinite risk" can be seen as the least bad concept in some areas and "xrisks" and "human risk of ruin" the least bad in others.

The purpose of this report is to establish a methodology to identify a very specific group of risks as well as continue to a process where these risks will be addressed in a systematic and appropriate way. The issue of naming this group of risks will be left to others. The important is that the category gets the attention it deserves.

2.4 Methodology [70]

This chapter presents the methodology used to identify global risks with potential infinite impact.

Methodology overview

In order to establish a list of global risks with potential infinite impact a methodological triangulation was used, consisting of:

– A quantitative assessment of relevant literature.
– A strategic selection of relevant organisations and their priorities.
– A qualitative assessment with the help of expert workshops.

2.4.1 A scientific review of key literature [71]

The scientific review of literature was led by Seth Baum, Executive Director of the Global Catastrophic Risk Institute[72] and research scientist at the Center for Research on Environmental Decisions, Columbia University.[73]

The methodology for including global risks with a potential infinite impact is based on a scientific review of key literature, with focus on peer-reviewed academic journals, using keyword search of both World of Knowledge[74] and Google Scholar[75] combined with existing literature overviews in the area of global challenges. This also included a snowball methodology where references in the leading studies and books were used to identify other scientific studies and books.

In order to select words for a literature search to identify infinite impacts a process was established to identify words in the scientific literature connected to global challenges with potentially infinite impacts. Some words generate a lot of misses, i.e. publications that use the term but are not the focus of this report. For example "existential risk" is used in business; "human extinction" is used in memory/cognition. Some search terms produced relatively few hits.

For example "global catastrophic risk" is not used much. Other words are only used by people within a specific research community: few use "existential risk" in our sense unless they are using Nick Bostrom's work. The term "global catastrophe" was identified as a phrase that referred almost exclusively to extremely negative impacts on humans, by a diversity of researchers, not just people in one research community.

A list of 178 relevant books and reports was established based on what other studies have referred to, and/or which are seen as landmark studies by groups interviewed during the process. They were selected for a closer examination regarding the challenges they include.[76]

The full bibliography, even with its focus on publications of general interest, is still rather long. So it is helpful to have a shorter list focused on the highlights, the most important publications based on how often they are quoted, how well-spread the content (methodology, lists, etc.) is and how often key organisations use them. The publications included must meet at least one of the following criteria:

– Historical significance. This includes being the first publication to introduce certain key concepts, or other early discussions of global challenges. Publications of historical significance are important for showing the intellectual history of global challenges. Understanding how the state of the art research got to where it is today can also help us understand where it might go in the future.

– Influential in developing the field. This includes publications that are highly cited[77] and those that have motivated significant additional research. They are not necessarily the first publications to introduce the concepts they discuss, but for whatever reason they will have proved important in advancing research.

– State of the art. This includes publications developing new concepts at the forefront of global challenges research as well as those providing the best discussions of important established concepts. Reading these publications would bring a researcher up to speed with current research on global challenges. So they are important for the quality of their ideas.

– Covers multiple global challenges (at least two). Publications that discuss a variety of global challenges are of particular importance because they aid in identifying and comparing the various challenges. This process is essential for research on global risks to identify boundaries and research priorities.

In order to identify which global challenges are most commonly discussed, key surveys were identified and coded. First, a list of publications that survey at least three global challenges was compiled, and they were then scanned to find which challenges they discussed.

The publications that survey many global challenges were identified from the full bibliography. Publications from both the academic and popular literature were considered. Emphasis was placed on publications of repute or other significance.[78] To qualify as a survey of global challenges, the publication had to provide an explicit list of challenges or to be of sufficient length and breadth for it to discuss a variety of challenges. Many of the publications are books or book-length collections of articles published in book form or as special issues of scholarly journals. Some individual articles were also included because they discussed a significant breadth of challenges.

A total of 40 global challenge survey publications were identified. For authors with multiple entries (Bostrom with three and WEF with ten) each challenge was counted only once to avoid bias.

In terms of authorship and audience, there are 17 academic publications, 9 popular publications, 1 government report, 3 publications written by academics for popular audiences. In terms of format, there are 15 books, 5 edited collections, 7 articles, 3 of miscellaneous format. Of the 40 publications identified, 22 were available at the time of coding. In addition 10 Global Risks Reports from the World Economic Forum were coded and then gathered under one heading: "WEF Global Risk Report 2005-2014".

A list of 34 global challenges was developed based on the challenges mentioned in the publications. A spreadsheet containing the challenges and the publications was created to record mentions of specific challenges in each publication to be coded.

Then each publication was scanned in its entirety for mentions of global challenges. Scanning by this method was necessary because many of the publications did not contain explicit lists of global challenges, and the ones that did often mentioned additional challenges separately from their lists. So it was not required that a global challenge be mentioned in a list for it to be counted – it only had to be mentioned somewhere in the publication as a challenge.

Assessing whether a particular portion of text counts as a global challenge and which category it fits in sometimes requires some interpretation. This is inevitable for most types of textual analysis, or, more generally, for the coding of qualitative data. The need for interpretation in this coding was heightened by the fact that the publications often were not written with the purpose of surveying the breadth of global challenges, and even the publications that were intended as surveys did not use consistent definitions of global challenges.

The coding presented here erred on the side of greater inclusivity: if a portion of text was in the vicinity of a global challenge, then it was coded as one. For example, some publications discussed risks associated with nuclear weapons in a general sense without specifically mentioning the possibility of large-scale nuclear war. These discussions were coded as mentions of nuclear war, even though they could also refer to single usages of nuclear weapons that would not rate as a global challenge.

This more inclusive approach is warranted because many of the publications were not focused exclusively on global challenges. If they were focused on them, it is likely that they would have included these risks in their global challenge form (e.g., nuclear war), given that they were already discussing something related (e.g., nuclear weapons). Below are the results from the overview of the surveys.

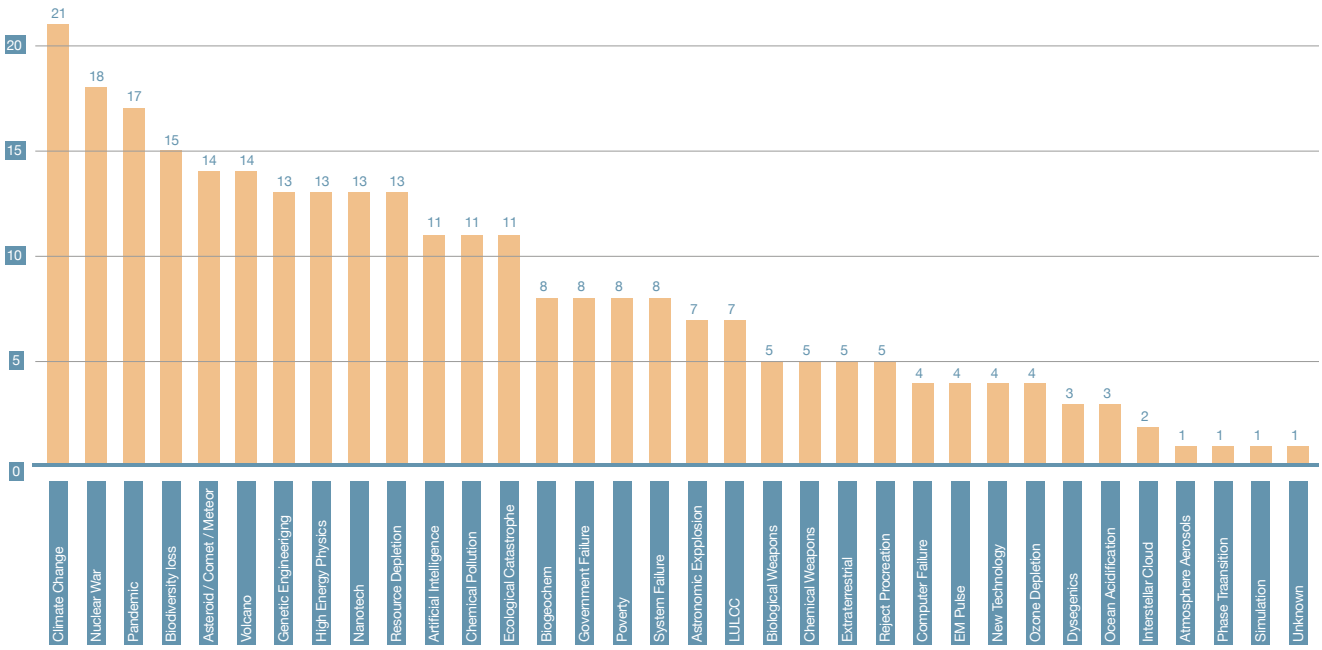


Figure 9: Number of times global challenges are included in surveys of global challenges

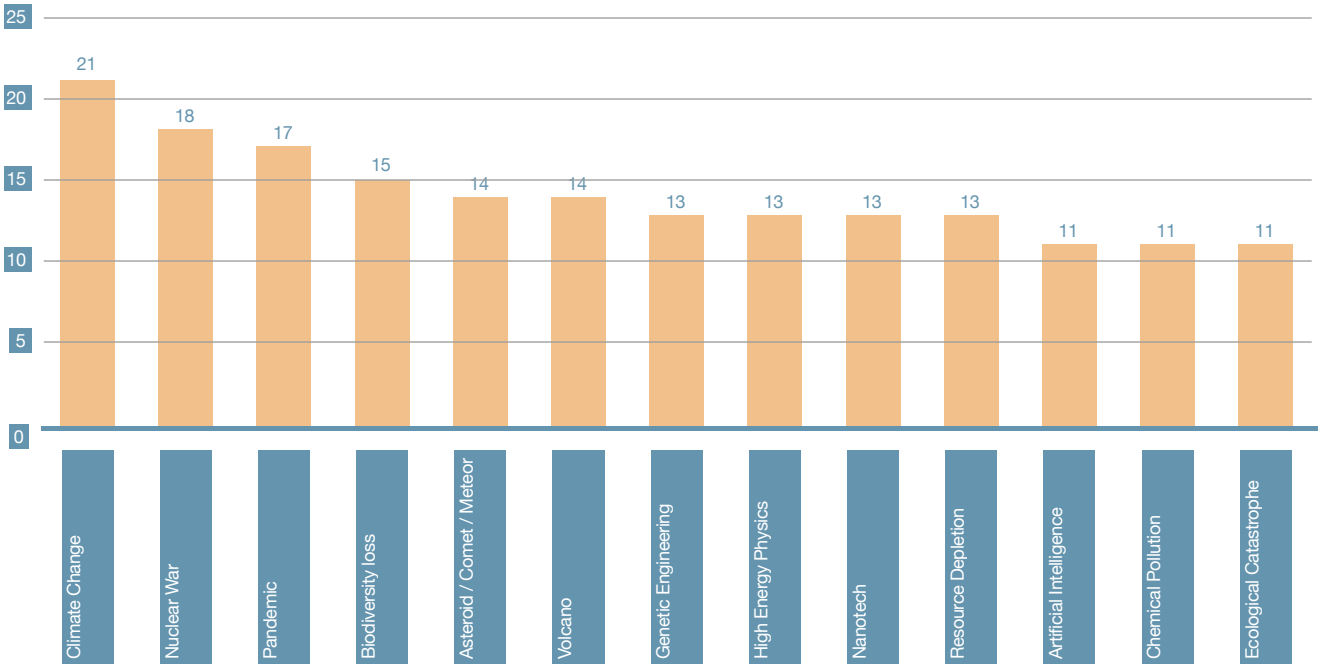


Figure 10: The global challenges included ten times or more in surveys of global challenges

It should be noted that the literature that includes multiple global challenges with possible infinite impact is very small, given the fact that it is about the survival of the human race.

Experts in the field of global challenges, like Nick Bostrom, have urged policymakers and donors to focus more on the global challenges with infinite impacts and have used dramatic rhetoric to illustrate how little research is being done on them compared with other areas.

It is however important to note that many more studies exist that focus on individual global risks, but often without including low-probability high-impact outcomes.[80]

How much work actually exists on human extinction infinite impact is therefore difficult to assess.

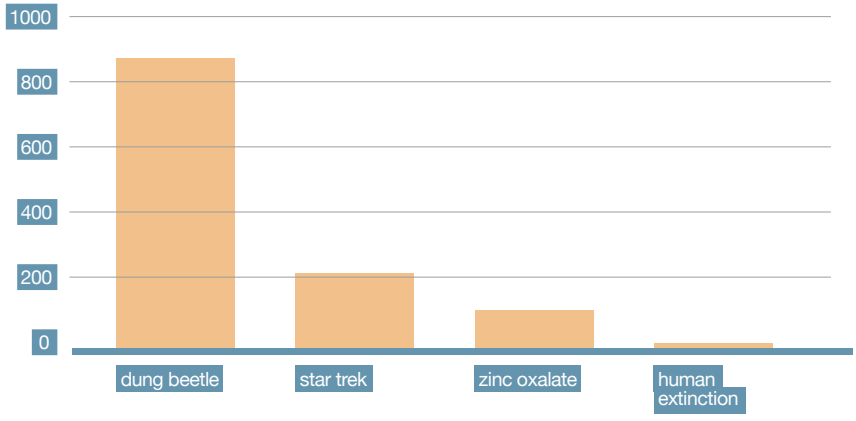


Figure 11: From the paper "Existential Risk Prevention as Global Priority" [79]

2.4.2 A review of organisations working on global challenges [81]

The list of risks found in the scientific literature was checked against a review of what challenges key organisations working on global challenges include in their material and on their webpages. This was done to ensure that no important risk was excluded from the list.

The coding of key organisations paralleled the coding of key survey publications. Organisations were identified via the global catastrophic risk organisation directory published by the Global Catastrophic Risk Institute.[82] They were selected from the directory if they worked on a variety of global challenges – at least three, and ideally more. The reason for focusing on those that work on multiple challenges is to understand which challenges they consider important and why. In contrast, organisations that focus on only one or two challenges may not

be able to adjust their focus according to which challenges they consider the most important.

The organisation coding used the same coding scheme developed for coding survey publications. References to specific global challenges were obtained from organisations' websites. Many have web pages which list the topics they work on. Where possible, references to global challenges were pulled from these pages. Additional references to these challenges were identified by browsing other web pages, including recent publications. While it is possible that some of these organisations have worked on global challenges not mentioned on the web pages that were examined, overall the main challenges that they have worked on have probably been identified and coded. So the results should give a reasonably accurate picture of what global challenges these organisations are working on.

Organisations working with global challenges were initially selected on the basis of the literature overview. A snowball sampling was conducted based on the list of organisations identified, according to whether they claimed to work on global challenges and/or their web page contained information about "existential risk", "global catastrophic risk","human extinction" or "greatest global challenges". Cross-references between organisations and input during the workshops were also used to identify organisations.

An initial list of 180 organisations which work with global challenges was established. Based on the production of relevant literature, which other organisations referred to the organisation, and/or are seen as influential by groups interviewed during the process a short-list of organisations were selected for a closer examination regarding the challenges they work with.

Then those working with multiple challenges were selected, resulting in a list of 19 organisations.[83]

Below is the overview of the results from the overview of key organisations working with multiple global challenges.

The organisations working on global challenges vary widely in:

1. What they count as a global challenge
2. How systematically they identify global challenges; and
3. **Their emphasis** on the most important global challenges

For most organisations working with global challenges there are no explanations for the methodology used to select the challenges. Only a few thought leaders, like Tower Watson and their Extreme Risk Report 2013, have a framework for the challenges and estimates of possible impacts.

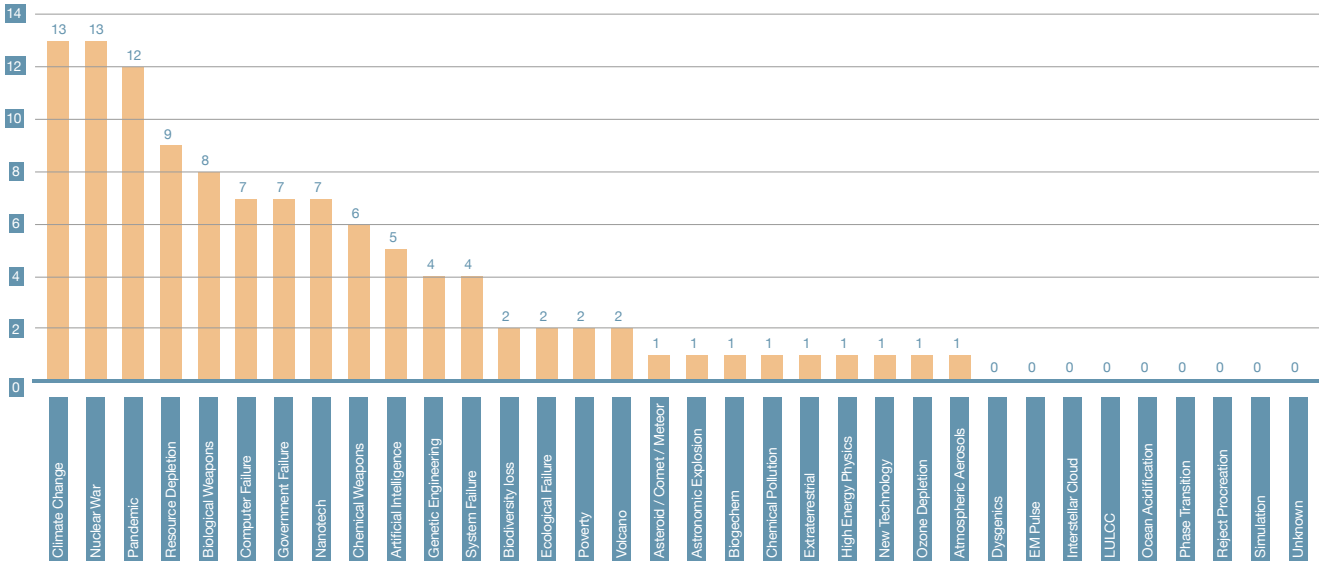


Figure 12: Global challenges that key prganisations work with

In most cases there is neither a definition of the impact, nor a definition of the probability. The report that focuses on global risk which is probably best known is the WEF Global Risk Report. The WEF's risk work, with many other groups', is probably best described as belonging to the category of risk perception rather than risk assessment, where experts are asked to estimate risks, but without any clear definition of probability or impact. The more serious organisations, like the WEF, also clearly define what they do as discussing perception of risk, not a scientific assessment of the actual risk.

The WEF describes its perception methodology as follows: "This approach can highlight areas that are of most concern to different stakeholders, and potentially galvanise shared efforts to address them." [85]

The question which people are asked to answer is: "What occurrence causes significant negative impact for several countries and industries?" [86]

The respondents are then asked to provide a number on two scales from 1-4, one for impact and another for likelihood (within 10 years).[87]

It is then up to the respondent to define what 1-4 means, so the major value of the report is to track the changes in perception over the years. Such perception approaches are obviously very interesting and, as the WEF states, can influence actual probability as the readers' decisions will be influenced by how different challenges are perceived. Still, it is important to remember that the report does not provide an assessment of the actual probability (0-100%) or an assessment of the impact (and not the impact on human suffering, as many respondents likely define risk in monetary terms for their own company or country).

An overview of WEF reports from the last ten years indicates that the challenges that likely could happen when applying a five year horizon, like the first signs of climate change, governmental failure and traditional pandemic, are identified.

On the other hand, challenges which have very big impacts but lower probability, like extreme climate change, nanotechnology, major volcanoes, AI, and asteroids, tend to get less, or no, attention.

An important question to explore is whether a focus on the smaller but still serious impacts of global challenges can result in an increased probability of infinite impacts. For example, there are reasons to believe that a focus on incremental adaptation instead of significant mitigation could be a problem for climate change as it could result in high-carbon lock-in.[88]

Other research indicates that focus on commercially relevant smaller pandemics could result in actions that make a major pandemic more likely. It is argued that this could happen, for example, by encouraging increased trade of goods while investing in equipment that scans for the type of pandemics that are known. Such a system can reduce the probability for known pandemics while at the same time resulting in an increased probability for new and more serious pandemics.[89]

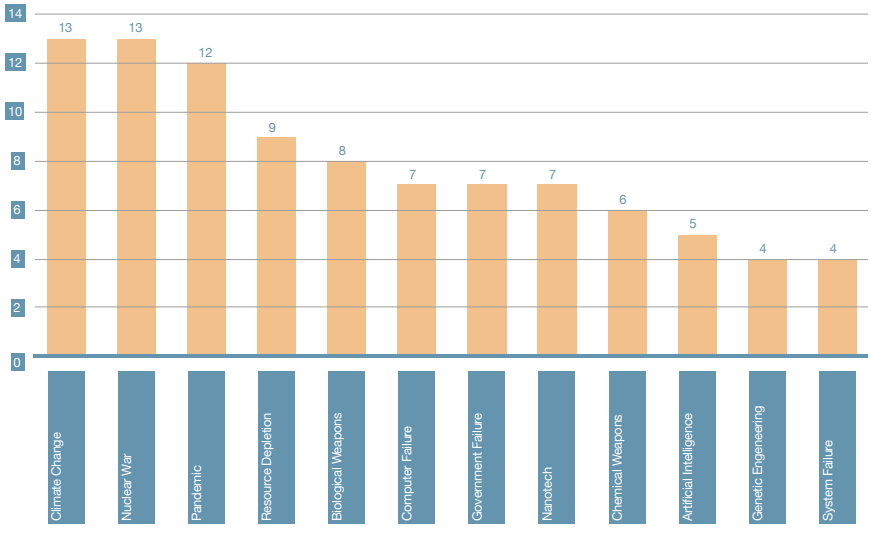


Figure 13: The top 12 global challenges that key organisations work with

2.4.3 Workshops

Two workshops were arranged where the selection of challenges was discussed, one with risk experts in Oxford at the Future of Humanity Institute and the other in London with experts from the financial sector. See Appendix 2 for agenda and participants.

In both workshops the list of global challenges was discussed to see if any additional challenges should be included, or if there were reasons to exclude some from the list.

No challenge was excluded at the workshops, but one was added. Although little research exists yet that is able to verify the potential impacts, the participants agreed to include Global System Collapse as a risk with possible infinite impact. There was agreement that further research is needed to clarify exactly what parts of the economic and political system could collapse and result in a potentially infinite outcome. The conclusion was that enough research exists to include such a collapse on the list.

2.5 The list of global risks

Based on the risks identified in the literature review and in the review of organisations and applying the criteria for possible infinite impact, these risks were identified:

1. Extreme Climate Change
2. Nuclear War
3. Global Pandemic
4. Ecological Catastrophe
5. Global System Collapse
6. Major Asteroid Impact
7. Supervolcano
8. Synthetic Biology
9. Nanotechnology
10. Artificial Intelligence (AI)
11. Unknown consequences
12. Future Bad Global Governance

This is an initial list. Additional risks will be added as new scientific studies become available, and some will be removed if steps are taken to reduce their probability[90] and/or impact so that they no longer meet the criteria.

Four categories of global challenges
The challenges included in this report belong to four categories. The first, current challenges, includes those where decisions today can result directly in infinite impacts. They are included even if the time between action and impact might be decades, as with climate change.

The second category is exogenous challenges, those where decisions do not – currently – influence probability, but can influence impact.

The third category is emerging challenges, those where technology and science are not advanced enough to pose a severe threat today, but where the challenges will probably soon be able to have an infinite impact. The technologies included in emerging challenges, including synthetic biology, nanotechnology and artificial intelligence (AI), will be critical to finding solutions to infinite impacts. Including these technologies should not be seen as an attempt to arrest them. If anything, the development of sustainable solutions should be accelerated. But it is equally important to create guidelines and frameworks to avoid their misuse, whether intentional or accidental.

The fourth category, future global policy challenges, is of a different kind. It includes challenges related to the consequences of an inferior or destructive global governance system. This is especially important as well-intended actions to reduce global challenges could lead to future global governance systems with destructive impact.

The first category, current challenges, includes:

1. Extreme Climate Change
2. Nuclear War
3. Global Pandemic
4. Ecological Catastrophe
5. Global System Collapse

The second category, exogenous challenges, covers:

6. Major Asteroid Impact
7. Supervolcano

Those in the third category, emerging challenges, are:

8. Synthetic Biology
9. Nanotechnology
10. Artificial Intelligence (AI)
11. Unknown consequences

The fourth category, global policy challenges, is:

12. Future bad governance

2.5.1 Risks not included

Many risks could severely damage humanity but have not been included in this report. They were excluded for one or more of three reasons:

1. Limited impact. Many challenges can have significant local negative effects, without approaching the "2 billion negatively affected" criterion - tsunamis, for example, and chemical pollution.

2. No effective countermeasures. The report focuses on promoting effective interventions and so ignores challenges where nothing useful can be done to prevent or mitigate the impact, as with nearby gamma-ray bursts.

3. Included in other challenges. Many challenges are already covered by others, or have a damage profile so similar that there seemed no need to have a separate category. Population growth, for one, is an underlying driver significant for climate change and eco-system catastrophe, but without direct large-scale impacts.

The challenges mentioned in the reviewed literature and organisations which are not included in this report often refer to economic damage such as "fiscal crises" or "unemployment". While such impacts could have far-reaching consequences they are obviously of another magnitude than those included here.

Some of the risks that were suggested and/or which exist in books and reports about global risks were rejected according to the criteria above. They include: [91]

1. Astronomical explosion/nearby gamma-ray burst or supernova.[92] These seem to be events of extremely low probability and unlikely to be survivable. Milder versions of them (where the source is sufficiently far away) may be considered in a subsequent report.

   => Not included due to: No effective countermeasures

2. False vacuum collapse. If our universe is in a false vacuum and it collapses at any point, the collapse would expand at the speed of light destroying all organised structures in the universe.[93] This would not be survivable.

   => Not included due to: No effective countermeasures

3. Chemical pollution. Increasingly, there is particular concern about three types of chemicals: those that persist in the environment and accumulate in the bodies of wildlife and people, endocrine disruptors that can interfere with hormones, and chemicals that cause cancer or damage DNA.

   => Not included due to: Limited impact

4. Dangerous physics experiments creating black holes/strangelets including high energy physics. These risks are of low probability[94] and have been subsumed under "Uncertain Risks".

   => Not included due to: Included in other challenges

5. Destructive solar flares. Though solar flares or coronal mass ejections could cause great economic damage to our technological civilisation,[95] they would not lead directly to mass casualties unless the system lacks basic resilience . So they have been subsumed in the Global System Collapse category.

   => Not included due to: Limited impact/included in other challenges

6. Moral collapse of humanity. Humanity may develop along a path that we would currently find morally repellent. The consequences of this are not clear-cut, and depend on value judgements that would be contentious and unshared.[96] Some of these risks (such as global totalitarianism or enduring poverty) were included in the Governance Disasters category.

=> Not included due to: Included in other challenges

7. Resource depletion/LULCC/ Biodiversity loss. It has often been argued that declining resources will cause increased conflict.[97] Nevertheless such conflicts would not be sufficient in themselves to threaten humanity on a large scale, without a " System Collapse" or "Governance Disasters". In the same way Land-use and land-cover change (LULCC) and biodiversity loss is submersed in ecological collapse if the impact is beyond the infinite threshold.

=> Not included due to: Included in other challenges

8. New technological experimental risks. It is possible and plausible that new unexpected technological risks will emerge due to experiments. However, until we know what such risks may be, they are subsumed in the "Uncertain Risks" category.

=> Not included due to: Included in other challenges

9. Genocides. Though immense tragedies in restricted areas, past genocides have remained contained in space and time and haven't spread across the globe.[98]

=> Not included due to: Limited impact

10. Natural disasters. Most natural disasters, like tsunamis and hurricanes, have no likelihood of causing the extent of casualties[100] needed for consideration on this list, as they are geographically limited and follow relatively mild impact probability curves.

=> Not included due to: Limited impact

11. Computer failure/Cyber-warfare. Though an area of great interest and research, cyber-warfare has never caused mass casualties and would be unlikely to do so directly. It may be the subject of a future report, but in this report it is considered to be a subset of warfare and general destabilising risks.

=> Not included due to: Limited impact /Submersed in other challenges

12. Underlying trends, e.g. overpopulation. Though increased population will put strains on resources and can contribute to increased probability for other challenges included in this report (such as climate change and ecosystem catastrophe), plausible population levels will not cause any direct harm to humanity.[101] Population growth is however an important trend that is significantly affecting several risks.

=> Not included due to: Limited impact / Submersed in other challenges

Note: Important underlying trends are discussed in chapter 5.

2.6 Relationship between impact levels beyond the infinite threshold

Complex systems are often stable only within certain boundaries. Outside these boundaries the system can collapse and rapidly change to a new stable state, or it can trigger a process where change continues for a long time until a new stable state is found.

Sometimes it can take a very long time for a system to stabilise again. Looking at all the biotic crises over the past 530 million years, a research team from Berkeley found an average of 10 million years between an extinction and a subsequent flourishing of life.[102]

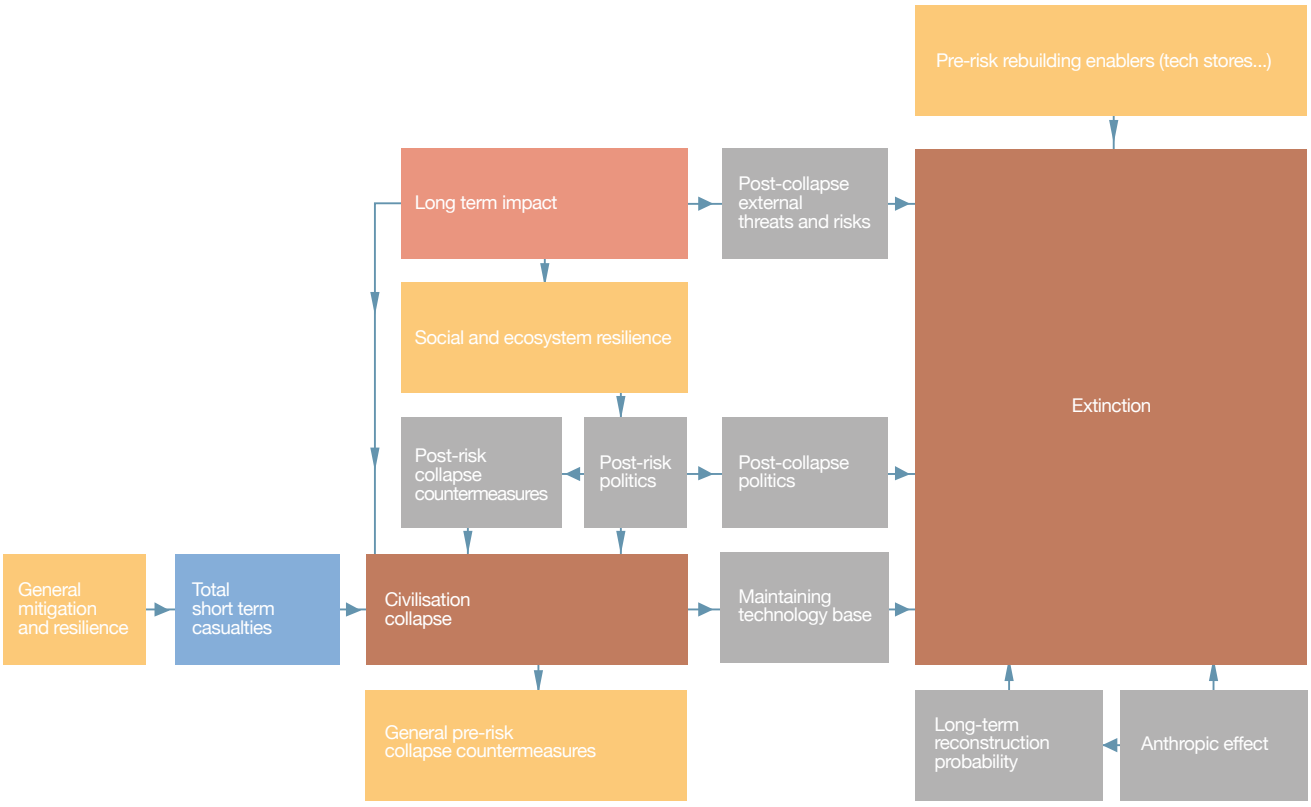
What makes things difficult is that once a system is unstable a small disaster can have knock-on effects – the death of one Austrian nobleman can result in an ultimatum which draws in neighbours until Australians end up fighting Turks and the First World War is well under way, to be followed by communism, the Second World War and the Cold War.

The challenge of understanding complex systems includes the fact that many of them have multiple attractors, including what are called "strange attractors".[103] Changes are close to linear as long as the system does not change very much, but once it is pushed out of balance it will get closer to other attractors, and when those become strong enough the system will tend to move towards chaos until a new balance is achieved around the new attractor.[104]

None of the risks in this report is likely to result directly in an infinite impact, and some cannot do so physically. All the risks however are big enough to reach a threshold where the social and ecological systems become so unstable that an infinite impact could ensue, as the graph below shows.

This graph and its accompanying text explain how an event that reaches a threshold level could cascade into even worse situations, via civilisation collapse[105] to human extinction.

The graph also seeks to illustrate the importance of ensuring ecological and social resilience, the two major insurance policies we have against a negative spiral after a major impact that takes us beyond the infinite threshold.



1. Social and ecosystem resilience. Resilient systems are naturally resistant to collapse, though this often comes at the cost of efficiency.[106] The more resilient the system, the more likely it is to be able to adapt to even large disasters. Improving resilience ahead of time can improve outcomes, even if the nature of the disaster isn't known.

2. General pre-risk collapse countermeasures. This category consists of all those measures put into place ahead of time to prevent civilisation collapse. It could include, for instance, measures to ensure continuity of government or prevent breakup of countries (or to allow these breakups to happen with the minimum of disruption). At the same time it should be noted that these kinds of measures could also trigger the breakdown.

3. General mitigation and resilience. This category consists of all measures that can reduce the impact of risks and prevent them getting out of hand (excluding social and ecosystem measures, which are important and general enough to deserve their own category).

4. Pre-risk rebuilding enablers. On top of attempting to prevent collapses, measures can also be taken to enable rebuilding after a collapse.[107] This could involve building stores of food, of technology, or crucial reconstruction tools.[108] Alternatively, it could involve training of key individuals or institutions (such as the crews of nuclear submarines) to give them useful post-collapse skills.

5. Long-term impact. Some risks (such as climate change) have strong long-term impacts after years or even decades. Others (such as pandemics) are more likely to have only a short-term impact. This category includes only direct long-term impacts.

6. Post-risk politics. The political structures of the post-risk world (governmental systems, conflicts between and within political groupings, economic and political links between groups) will be important in determining if a large impact leads ultimately to civilisation collapse or if recovery is possible.

7. Post-risk collapse countermeasures. These are the countermeasures that the post-risk political structures are likely to implement to prevent a complete civilisation collapse.

8. Maintaining a technology base. Current society is complex, with part of the world's excess production diverted into maintaining a population of scientists, engineers and other experts, capable of preserving knowledge of technological innovations and developing new ones. In the simpler post-collapse societies, with possibly much lower populations, it will be a challenge to maintain current technology and prevent crucial skills from being lost.[109]

9. Post-collapse politics. Just as post-risk politics are important for preventing a collapse, post-collapse politics will be important in allowing a recovery. The ultimate fate of humanity may be tied up with the preservation of such concepts as human rights, the scientific method and technological progress.

10. Post-collapse external threats and risks. Simply because a risk has triggered the collapse of human civilisation, that does not mean that other risks are no longer present. Humanity will have much less resilience to deal with further damage, so the probability of these risks is important to determine the ultimate fate of humanity.

11. Anthropic effects. We cannot observe a world incapable of supporting life, because we could not be alive to observe it. When estimating the likelihood of disasters and recovery it is very important to take this effect into consideration and to adjust probability estimates accordingly.[110]

12. Long-term reconstruction probability. A post-collapse world will differ significantly from a pre-industrial revolution world. Easy access to coal and oil will no longer be possible. In contrast, much usable aluminium will have been extracted and processed and will be left lying on the surface for easy use. Thus it will be important to establish how technically possible it may be to have a second industrial revolution and further reconstruction up to current capabilities without creating the problems that the first industrial revolution resulted in.

3. Twelve Global Challenges

You may choose to look the other way but you can never say again that you did not know."

William Wilberforce

For the selection of events information from specialised bodies and scientific journals in the area of global risk was gathered.[111] Using keywords related to the various risks a global selection of events was sought, along with original sourcing in academic or official sources.

The list of events was then ranked based on their risk relevance, i.e. their effect on the probability and/or the impact of the challenge.

To finalise the list, a group of experts was consulted by email and a draft overview of the challenges was presented at a workshop at the Future of Humanity Institute (FHI) in Oxford, where additional input was provided on selection and content. Issue experts were then consulted before the final list of events was established. [112]

Four categories were used to classify the different events:

1. Policy: Global or national policy initiatives that affect probability and/or impact
2. Event: The challenge is made real in some way that is relevant for probability and/or impact
3. Research: New knowledge about probability and/or impact
4. Initiative: A stakeholder/group addressing the challenge in concrete ways to reduce probability and impact

Extreme Climate Change

Nuclear War


Global Pandemic


Ecological Catastrophe

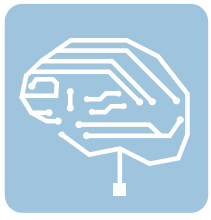

Global System Collapse


Major Asteroid Impact


Super-volcano


Synthetic Biology


Nanotechnology


Artificial Intelligence

Unknown Consequences


Future Bad Global Governance

3.1 Current risk

3.1.1 Extreme Climate Change

Climate change is a significant and lasting change in the statistical distribution of weather patterns over periods ranging from decades to millions of years. It may be a change in average weather conditions, or in the distribution of weather around the average conditions (i.e., more or fewer extreme weather events).

Extreme climate change is used to distinguish from the impacts beyond the dangerous climate that a 2° C temperature rise is expected to result in.[113]

3.1.1.1 Expected impact

Many of the expected impacts of climate change are well known, including a warming climate, more severe storms and droughts, rising sea levels, ocean acidification, and damage to vulnerable ecosystems.[114] As for all risks there are uncertainties in the estimates, and warming could be much more extreme than the middle estimates suggest. Models tend to underestimate uncertainty[115] (especially where impact on humanity is concerned,[116] where the effect also depends on modellers' choices such as the discount rate[117]), so there is a probability[118] that humanity could be looking at a 4°C[119] or even 6°C[120] warming in the coming decades. This could arise from positive feedback loops, such as the release of methane from permafrost[121] or the dieback of the Amazon rainforests,[122] that strengthen the warming effect. So far, efforts at curbing emissions have been only moderately successful and are still very far from what is needed.[123]

The impact of global warming, whether mild or severe, would be felt most strongly in poorer countries. Adaptation that can address significant warming is often very expensive,[124] and many of the poorest countries are in the tropics and sub-tropics that would be hardest hit (they could become completely uninhabitable for the highest range of warming[125]). Mass deaths and famines, social collapse and mass migration are certainly possible in this scenario.

Combined with shocks to the agriculture and biosphere-dependent industries of the more developed countries, this could lead to global conflict and possibly civilisation collapse – to the extent that many experts see climate change as a national security risk[126]. Further evidence of the risk comes from indications that past civilisation collapses have been driven by climate change.[127]

Extinction risk could develop from this if the remaining human groups were vulnerable to other shocks, such as pandemics, possibly exacerbated by the changed climate.[128] There is some evidence of 6°C climate change causing mass extinction in the past,[129] but a technological species such as ourselves might be more resilient to such a shock.

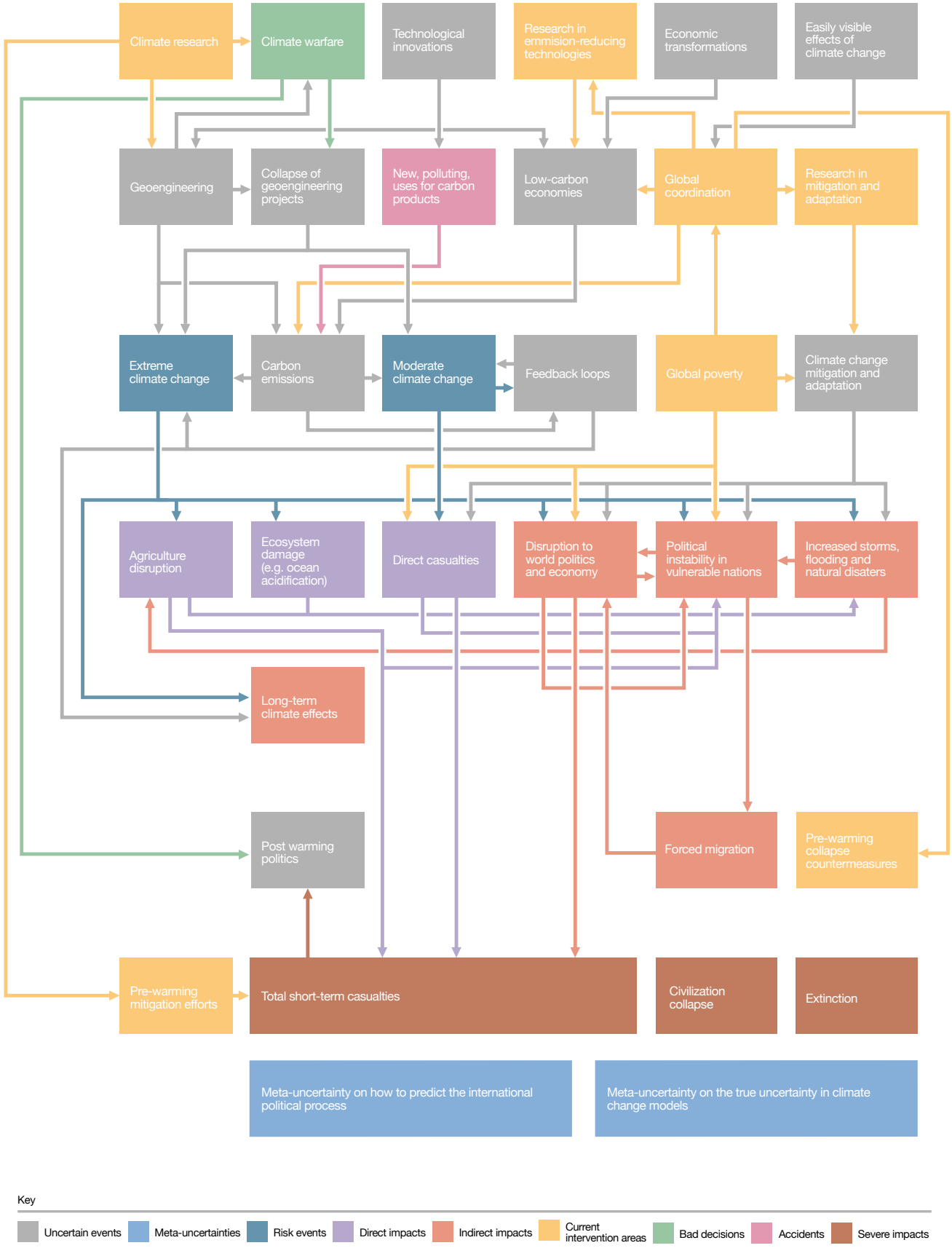
A unique feature of the climate change challenge is what is called geo-engineering.[130] Though this could - if it works - reduce many impacts at a relatively low cost, it would not do so evenly. Geo-engineering would possibly reduce the impacts of climate change in some countries, benefitting them while leaving others to suffer.[131] This could lead to greater political instability. One of the most popular geo-engineering ideas – stratospheric sulphate aerosols – suffers from the weakness that it must be continuous. [132]

If for any reason it stopped (such as a civilisation collapse), warming would resume at a significantly higher pace, reaching the point where it would have been without geo-engineering. The speed of this rebound would put extra pressure on the ecosystem and the world's political system. So the biggest challenge is that geo-engineering may backfire and simply make matters worse.[134]

3.1.1.2 Probability disaggregation

Five important factors in estimating the probabilities and impacts of the challenge:

1. The uncertainties in climate sensitivity models, including the tail.
2. The likelihood - or not - of global coordination on controlling emissions.
3. The future uptake of low-carbon economies, including energy, mobility and food systems.
4. Whether technological innovations will improve or worsen the situation, and by how much.
5. The long-term climate impact caused by global warming.


Climate research
Climate warfare
Technological innovations
Research in emmision-reducing technologies
Economic transformations
Easily visible effects of climate change
Geoengineering
Collapse of geoengineering projects
New, polluting, uses for carbon products
Low-carbon economies
Global coordination
Research in mitigation and adaptation
Extreme climate change
Carbon emissions
Moderate climate change
Feedback loops
Global poverty
Climate change mitigation and adaptation
Agriculture disruption
Ecosystem damage (e.g. ocean acidification)
Direct casualties
Disruption to world politics and economy
Political instability in vulnerable nations
Increased storms, flooding and natural disaters
Long-term climate effects
Post warming politics
Forced migration
Pre-warming collapse countermeasures
Pre-warming mitigation efforts
Total short-term casualties
Civilization collapse
Extinction
Meta-uncertainty on how to predict the international political process
Meta-uncertainty on the true uncertainty in climate change models
Key
Uncertain events
Meta-uncertainties
Risk events
Direct impacts
Indirect impacts
Current intervention areas
Bad decisions
Accidents
Severe impacts

1. Research which further refines our understanding of climate change and geo-engineering ideas will be essential in predicting change, preparing for it, and potentially reversing it. On the negative side, climate science research may allow the possibility of climate change tools being used for warfare.

2. Global poverty will affect both the vulnerability of many nations to the effects of climate change, and the likelihood of achieving global co-ordination earlier rather than later.

3. Pre-extreme warming mitigation efforts will affect the level of impact from climate change.

4. Pre-warming collapse countermeasures will affect the likelihood of civilisation collapse.

5. Research into mitigation and adaptation is necessary for effective implementation of either approach.
6. Research into emission-reducing technologies (such as alternative energies) will be important for transitioning to a low carbon economy.

7. Global coordination and cooperation will be key to funding mitigation/ adaptation research and development, and for the global control of carbon emissions or transitioning to a global low carbon economy.

8. Climate warfare is possible if geo-engineering and climate modification methods can be harnessed by nations to harm others.

9. New, more polluting uses of carbon would, if they had a strong economic rationale, put upwards pressure on carbon emissions.

10. The direct casualties of limited global warming are likely to be few, as humans can adapt to many different temperatures and climates. The indirect effect can however be significant, e.g. migration, starvation, extreme weather.

11. Climate change is likely to cause extensive ecosystem damage, such as ocean acidification and pressure on many sensitive species that cannot easily adapt to temperature changes.

12. Agriculture will be disrupted by increased temperature.

13. The direct and indirect effects of climate change will have a great impact on the world's political and economic systems, which will in turn determine the severity of the changes.

14. Many nations will be made politically vulnerable to the direct and indirect impacts of climate change, putting great pressure on their political systems and institutions.

15. Climate change will cause an increase in storms, floods, and other natural disasters. If political stability is maintained, most of the casualties are likely to result from these factors.

16. Forced migration from unstable or disrupted areas will put further pressure on more stable areas.

17. The long-term impact of climate change (including further carbon emissions and warming) will be important for determining the risk of collapse and subsequent rebuilding possibilities.

18. Attempts to mitigate and adapt to climate change will be important for reducing the severity of climate change's impact.

19. The level of carbon emissions is the driver of climate change, and will be crucial in determining its ultimate impact.

20. Feedback loops will be important in determining whether carbon emissions are self-damping or self-forcing (i.e. whether an extra ton of CO_2 emissions is likely to result in more or less than a ton in the atmosphere).

21. Transitioning to low carbon economies will be crucial for reducing emissions without disrupting the world's political or economic systems.

22. Geo-engineering offers the possibility of decreasing carbon concentration in the atmosphere alongside, or instead of, emission reductions. But it may make climate warfare a possibility.

23. If geo-engineering projects collapse in the middle of implementation, this could lead to strong warming over a dangerously short period of time.

24. Technological innovations will be crucial for transitioning to low carbon economies or allowing geo-engineering. But they may also result in new, carbon-intensive innovations, which, if sufficiently profitable, could push emissions up.

25. Some level of changes to the standard economic system may be needed to transition to low carbon economies.

26. Easily visible impacts of climate change may be instrumental in pushing better global coordination on the issue.

27. The political systems in place as warming increases will determine how well the world copes with a hotter planet.

28. Climate models are extremely detailed and inevitably uncertain. But the real level of uncertainty includes uncertainties about the models themselves.

29. The course of international politics is extremely hard to predict, even for political scientists.[135]

3.1.1.3 Main events during 2013

19-Apr-13: Launch of the report "Unburnable Carbon 2013: Wasted capital and stranded assets" [136]

– Research

To constrain the rise in global average temperature to less than 2°C above pre-industrial levels, a maximum of around 565 – 886 billion tonnes (Gt) of carbon dioxide could be emitted before 2050.[137] The world's proven fossil fuel reserves amount to 2,860 Gt of CO2, however, and are viewed as assets by companies and countries. Since it is likely that these assets cannot be realised, these entities are over-valued at current prices – arguably, a "carbon bubble."

The report provides evidence that serious risks are growing for high-carbon assets, and aims to help investors and regulators manage these risks more effectively and prepare for a global agreement on emissions reductions. It indirectly highlights part of the challenge of emissions reductions: they will mean the loss of highly valuable assets to corporations and governments.

02-May-13: CO2 at 400 PPM for the first time in > 800,000 years[138]

– Event

The Mauna Loa carbon dioxide record, also known as the "Keeling Curve," is the world's longest unbroken record of atmospheric CO2 concentrations. It recently reached 400 ppm (parts per million) of CO2. Such concentrations have not been reached for at least 800,000 years,[139] placing humanity in a historically unprecedented situation.

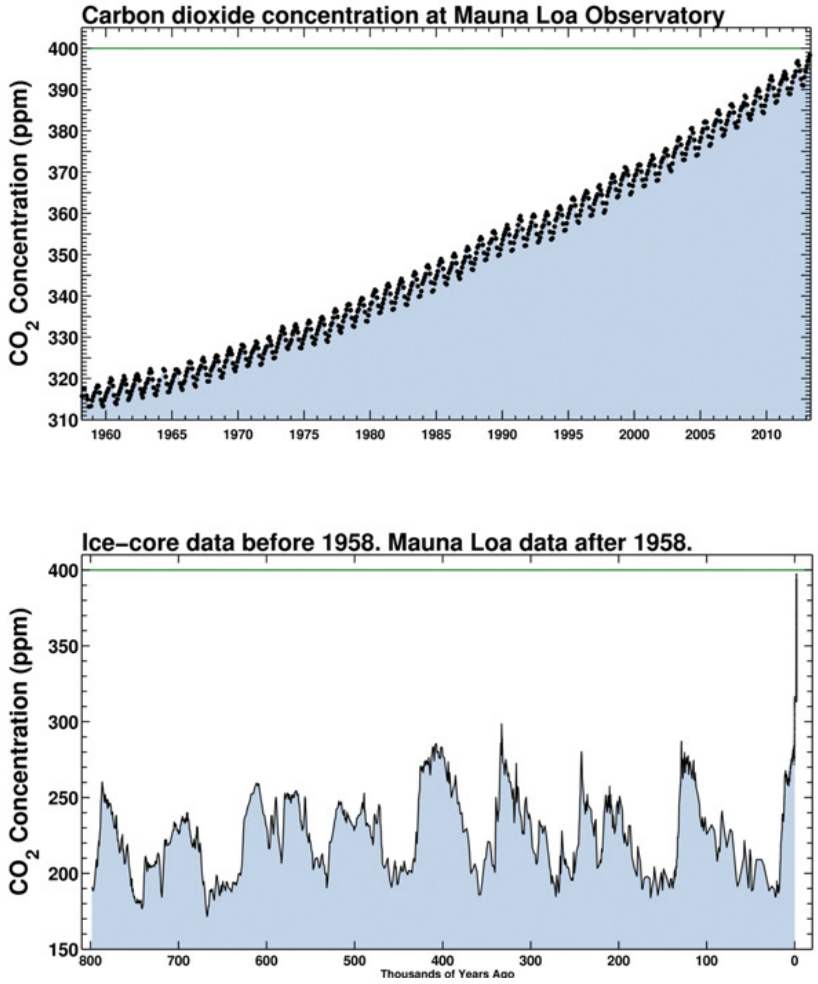
Prior to the Industrial Revolution, natural climate variations caused atmospheric CO2 to vary between about 200 ppm during ice ages and 300 ppm during the warmer inter-glacial periods. The last time concentrations were as high as they are now seems to have been during the Mid-Pliocene, about 3 million years before the present when temperatures were 2-3°C warmer, and in which geological evidence and isotopes agree that sea level was at least 15 to 25 m above today's levels with correspondingly smaller ice sheets and lower continental aridity.[140]

21-May-13: China agrees to impose carbon targets by 2016[141]

– Policy

Since China is the world's greatest emitter of CO2,[142] any reduction steps it takes can have a substantial impact. It has announced a "National Low Carbon Day",[143] a "series of major promotional events to improve awareness and get the whole society to address climate change." More practically, the Chinese government has agreed to impose carbon targets by 2016 - a ceiling on greenhouse gas emissions.[144]

Figure 14-15, Source: Scripps Institution of Oceanography, via http://blogs.scientificamerican.com/observations/2013/05/09/400-ppm-carbon-dioxide-in-the-atmosphere-reaches-prehistoric-levels



22-May-13: Private Sector Initiative - database of actions on adaptation[145]

– Initiative

Global warming is an externality[146] – a consequence of business decisions made by entities that do not bear the full cost of what they decide – so the drive to mitigate its effects is more likely to come from governmental or supra-governmental organisations. Nevertheless, the private sector has been involved in mitigation attempts for a variety of reasons, from investment opportunities to public relations. The United Nations Framework Convention on Climate Change (UNFCCC) maintains a database of some of these attempts, ranging from Ericsson's enabling access to climate services in Uganda, through BASF's development of new technologies for food security, Allianz insurers rewarding sustainable business practices, all the way to Chiles de Nicaragua's attempts to enable small agro-exporters to adapt to climate change – and many more.

The potential opportunities for private companies are listed as:

– New market opportunities and expansion;
– Development of climate-friendly goods and services;
– Potential cost savings;
– Risk reduction measures, including physical operations;
– Climate proofing the supply chain;
– Enhanced corporate social responsibility.

27-Sep-13: IPCC report: "Climate Change 2013: The Physical Science Basis" [147]

– Research

The 5th IPCC report "considers new evidence of climate change based on many independent scientific analyses from observations of the climate system, palaeoclimate archives, theoretical studies of climate processes and simulations using climate models." It concludes that:

– Warming of the climate system is unequivocal, and since the 1950s many of the observed changes are unprecedented over decades to millennia. The atmosphere and oceans have warmed, the amounts of snow and ice have diminished, sea level has risen, and the concentrations of greenhouse gases have increased

– Human influence on the climate system is clear. This is evident from the increasing greenhouse gas concentrations in the atmosphere, positive radiative forcing, observed warming, and understanding of the climate system. It is extremely likely that human influence has been the dominant cause of the observed warming since the mid-20th century.

– Each of the last three decades has been successively warmer at the Earth's surface than any preceding decade since 1850.

– Over the last two decades, the Greenland and Antarctic ice sheets have been losing mass, glaciers have continued to shrink almost worldwide, and Arctic sea ice and Northern Hemisphere spring snow cover have continued to decrease in extent.

– The rate of sea level rise since the mid-19th century has been larger than the mean rate during the previous two millennia (high confidence). Over the period 1901 to 2010, global mean sea level rose by 0.19 [0.17 to 0.21] m.

– The atmospheric concentrations of carbon dioxide, methane, and nitrous oxide have increased to levels unprecedented in at least the last 800,000 years. Carbon dioxide concentrations have increased by 40% since pre-industrial times, primarily from fossil fuel emissions and secondarily from net land use change emissions.

The report further predicted, amongst other points, that:

– Continued emissions of greenhouse gases will cause further warming and changes in all components of the climate system. Limiting climate change will require substantial and sustained reductions of greenhouse gas emissions.

– The oceans will continue to warm during the 21st century. Heat will penetrate from the surface to the deep ocean and affect ocean circulation. Further uptake of carbon by the oceans will increase ocean acidification. Global mean sea level will continue to rise during the 21st century.

– It is very likely that Arctic sea ice cover will continue to shrink and become thinner. Global glacier volume will further decrease.

– Most aspects of climate change will persist for many centuries even if emissions of CO2 are stopped.

27-Sep-13: Launch of the Global Risk and Opportunity Indicator (GROI) [148]
– Research

Launched by the Global Challenge Foundation, this Indicator is a web tool for illustrating quantified risks, with the objective of increasing awareness about global risks and opportunities and helping guide the changes required in the global governance system. The site is still under construction; the Foundation's aims are to achieve, by the end of 2014:

1. An interactive Global Risk & Opportunity Indicator that allows users to calculate the probability for any global warming, between one and ten degrees Celsius, at different greenhouse gas concentrations. The indicator will then be further developed to illustrate interdependencies with other global risks and highlight opportunities for minimising the risks. Subsequent development will allow users to change different underlying assumptions and see the corresponding change in risk.

2. Methodology and data to estimate probabilities for a number of climate impacts at different temperature levels, e.g., sea level rise, droughts, flooding and heat waves, as well as to explore the risk of runaway global warming.

3. Methodology and data to estimate the probability of existential climate threats, i.e., to estimate the risk that climate change impacts pose a significant threat to human civilisation – defined as a serious negative impact on at least two billion people.

23-Nov-13: Limited progress at Warsaw COP 19 climate negotiations [149]
– Policy

The global environment can be considered a global public good (i.e. non-excludable and non-rivalrous).[150] Economic theory claims that such goods will be undersupplied by the market.[151] Hence the importance of trans-national negotiations to address climate change.

Despite the importance of the subject, the main achievement of the Warsaw negotiations was to keep talks on track for more negotiations in 2015.[152] Though there was general agreement on the necessity of cutting carbon emissions, the dispute was over how to share the burden of doing so. In this instance, the debate was between more- and less-developed countries, with the latter demanding compensation from the former to help them cope with the burden of reducing emissions. That particular dispute was papered over,[153] but similar ones will be likely in future due to the range of different actors and their divergent agendas.[154]

03-Dec-13 Abrupt Impacts of Climate Change: Anticipating Surprises[155]
– Research

Climate change has been developing gradually, at least on the human scale[156] (though very rapidly on a geological timescale[157]). This may not continue, however: this paper looks at the potential for abrupt changes in physical, biological, and human systems, in response to steady climate change. It highlights two abrupt changes that are already under way: the rapid decline in sea ice[158] and the extinction pressure on species.[159] On the other hand, some widely discussed abrupt changes – the rapid shutdown of the Atlantic Meridional Overturning Circulation[160] and the rapid release of methane from either thawing permafrost[161] or methane hydrates[162] – are shown to be unlikely to occur this century.

The report argues that large uncertainties about the likelihood of some potential abrupt changes[163] highlight the need for expanded research and monitoring, and propose an abrupt change early warning system. The aim would be to foresee abrupt change before it occurs, and reduce the potential consequences.

3.1 Current risk

3.1.2 Nuclear War

After their use in Hiroshima and Nagasaki nuclear weapons have never been used in a conflict,but because they are extremely powerful and could cause destruction throughout the world, the possibility of nuclear war has had a great effect on international politics. [164]

3.1.2.1 Expected impact

The likelihood of a full-scale nuclear war between the USA and Russia has probably decreased in recent decades due to some improvements in relations between these two countries and reductions in the size of their arsenals. Still, the potential for deliberate or accidental[165] nuclear conflict has not been removed, with some estimates putting the risk of nuclear war in the next century or so at around 10%[166] – it may have been mostly down to luck that such a war did not happen in the last half century[167].

A nuclear war could have a range of different impacts. At the lowest end is the most obvious and immediate impact: destruction and death in major cities across the world, due to the explosions themselves and the radioactive fallout. But even if the entire populations of Europe, Russia and the USA were directly wiped out in a nuclear war – an outcome that some studies have shown to be physically impossible[168], given population dispersal and the number of missiles in existence[169] – that would not raise the war to the first level of impact, which requires > 2 billion affected.[170]

A larger impact would depend on whether or not the war triggered what is often called a nuclear winter or something similar.[171] The term refers to the creation of a pall of smoke high in the stratosphere that would plunge temperatures below freezing around the globe and possibly also destroy most of the ozone layer.[172]

The detonations would need to start firestorms in the targeted cities, which could lift the soot up into the stratosphere.[173]

There are some uncertainties about both the climate models and the likelihood of devastating firestorms,[174] but the risks are severe and recent models[175] have confirmed the earlier[176] analysis. Even a smaller nuclear conflict (between India and Pakistan, for instance) could trigger a smaller nuclear winter which would place billions in danger.[177]

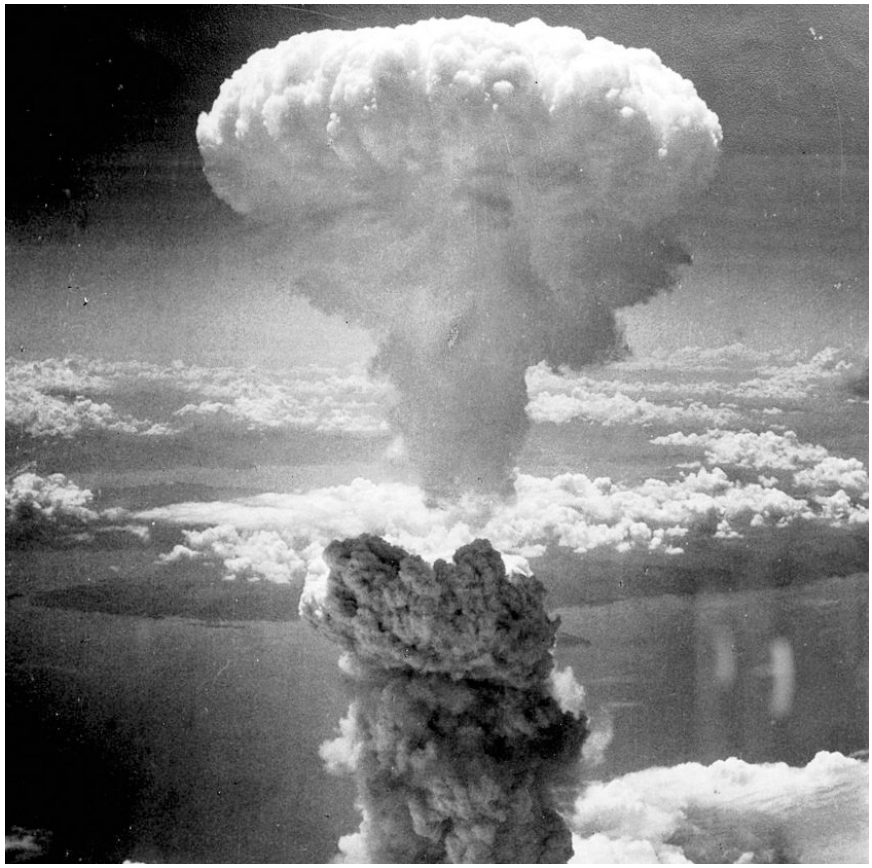
The disintegration of the global food supply would make mass starvation and state collapse likely. As the world balance of power would be dramatically shifted and previous ideological positions called into question, large-scale war would be likely. This could lead to a civilisation collapse.

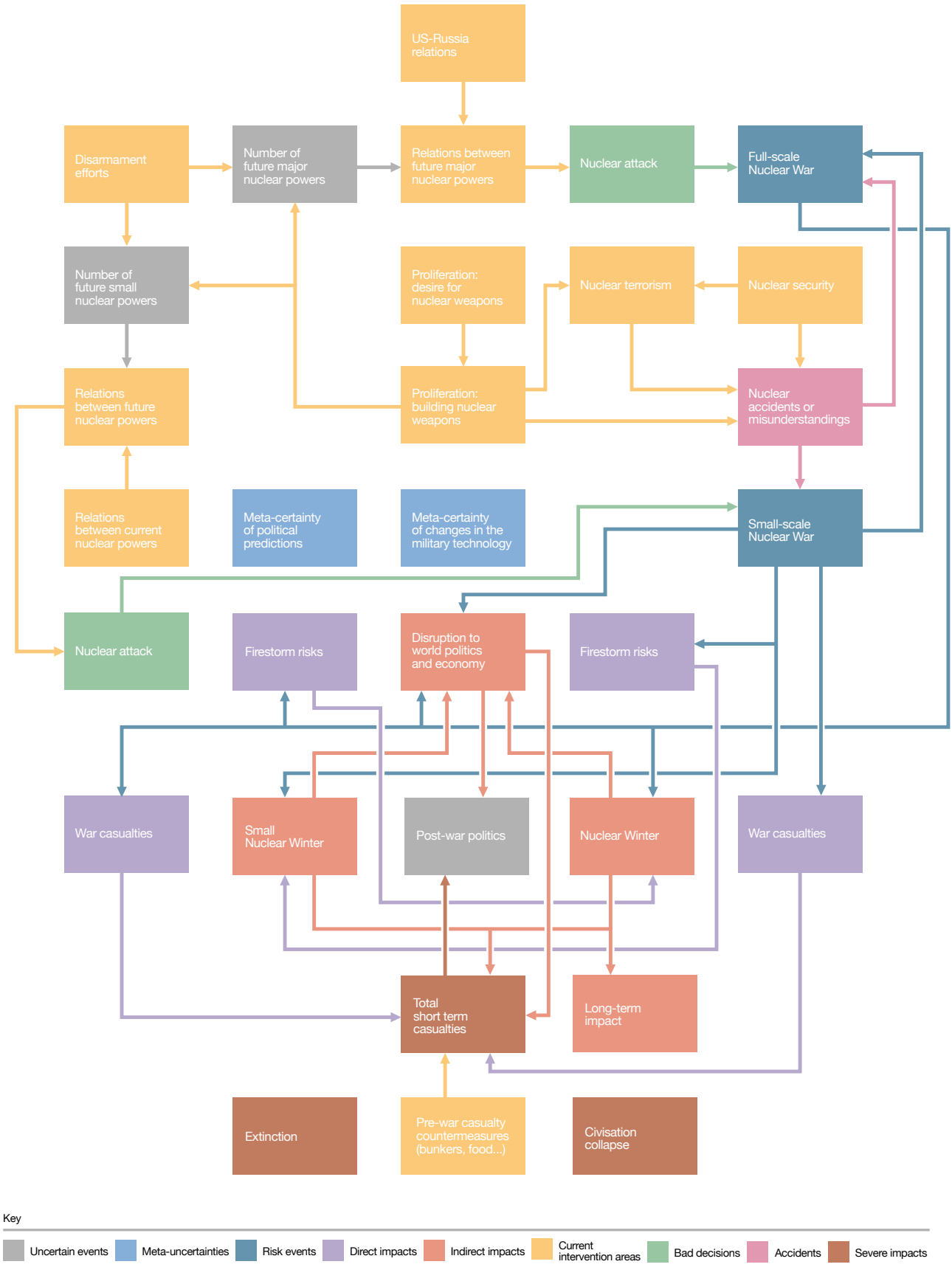
Extinction risk is only possible if the aftermath of the nuclear war fragments and diminishes human society to the point where recovery becomes impossible[178] before humanity succumbs[179] to other risks, such as pandemics.[180]

3.1.2.2 Probability disaggregation

Five important factors in estimating the probabilities and impacts of the challenge:

1. How relations between current and future nuclear powers develop.
2. The probability of accidental war.
3. Whether disarmament efforts will succeed in reducing the number of nuclear warheads.
4. The likelihood of a nuclear winter.
5. The long-term effects of a nuclear war on climate, infrastructure and technology.




US-Russia relations
Disarmament efforts
Number of future major nuclear powers
Relations between future major nuclear powers
Nuclear attack
Full-scale Nuclear War
Number of future small nuclear powers
Proliferation: desire for nuclear weapons
Nuclear terrorism
Nuclear security
Relations between future nuclear powers
Proliferation: building nuclear weapons
Nuclear accidents or misunderstandings
Relations between current nuclear powers
Meta-certainty of political predictions
Meta-certainty of changes in the military technology
Small-scale Nuclear War
Nuclear attack
Firestorm risks
Disruption to world politics and economy
Firestorm risks
War casualties
Small Nuclear Winter
Post-war politics
Nuclear Winter
War casualties
Total short term casualties
Long-term impact
Extinction
Pre-war casualty countermeasures (bunkers, food...)
Civisation collapse
Key
Uncertain events
Meta-uncertainties
Risk events
Direct impacts
Indirect impacts
Current intervention areas
Bad decisions
Accidents
Severe impacts

1. The success or failure of disarmament will determine the number of nuclear warheads available for a future nuclear conflict.

2. The first step of proliferation is countries desiring to possess nuclear weapons. Various political interventions may reduce or increase this desire.

3. The second step of proliferation is countries building nuclear weapons. Various mechanisms, agreements and inspections may be relevant

4. Nuclear terrorism may be the trigger of a larger nuclear conflict, especially if the detonation is misinterpreted as a traditional attack.

5. The security of nuclear weapons and materials affects both the probability of nuclear terrorism and the control likelihood of nuclear accidents.

6. The relations between future nuclear powers will be the major determinant of whether a nuclear war breaks out.

7. The relations between current nuclear powers will be a major determinant of the relations between future nuclear powers.

8. The relations between future major nuclear powers will be the major component of determining whether a major nuclear war breaks out.

9. Relations between the USA and Russia (the only current major nuclear powers) will be a major determinant of the relations between future major nuclear powers.

10. Pre-war countermeasures (such as nuclear bunkers and food stores) can help mitigate the casualties of a smaller nuclear conflict.

11. A small-scale nuclear war could start with an attack by one or more nuclear powers.

12. A full-scale nuclear war could start with an attack by one or more major nuclear powers.

13. Aside from attacks, the other way a nuclear war could start would be through accidental firings or misinterpretations of other incidents.

14. Firestorms caused by burning cities are one of the main ways a nuclear conflict could cause major climate disruption, and hence high casualties.

15. The direct war casualties from a nuclear conflict are likely to be small compared with the potential climate effects.

16. A nuclear winter is the way in which a nuclear conflict could have the most damaging effects on the world.

17. Even a smaller nuclear conflict could trigger a smaller nuclear winter that could have major disruptive effects on agriculture hence human survival.

18. Any war will have a disruptive impact on the world's politics and economy. A nuclear conflict – possibly accompanied by a nuclear winter – even more so.

19. The long term impact of nuclear winter, infrastructure disruption, and possibly radiation, will determine the likelihood of collapse and rebuilding.

20. Since a nuclear power must be one of the parties to a nuclear war, the number of the former affects the probability of the latter.

21. Since a major nuclear power must be one of the parties to a major nuclear war, the number of the former affects the probability of the latter.

22. Post-war politics will be determined by the war, the disruption it caused, and the number of casualties it inflicted.

23. Unlike other risks, nuclear weapons are targeted by humans, so may take out important parts of the world's infrastructure (and conventional weapons used in a conflict may have the same effect).

24. Unlike other risks, nuclear weapons are targeted by humans, so may take out important parts of the world's technology and research base (and conventional weapons used in a conflict may have the same effect).

25. Maintaining a technology base will be complicated by the possible targeting of infrastructure and the technology base during a conflict.

26. The further development of military technology is hard to predict. The current balance of power under MAD (mutually assured destruction) is based on certain assumptions about the effectiveness of nuclear weapons, such as second strike capability. If this were removed (such as by effective submarine detection, or anti-ballistic missile shields), the effect on the balance of power is hard to predict.

27. The course of international politics is extremely hard to predict, even for political scientists.[181]

3.1.2.3 Main events during 2013

12-Feb-13: North Korea carries out third, largest nuclear test [182]

– Event

On 12 February 2013, North Korea carried out its third nuclear test. The test was condemned across the world, [183] and led to increased sanctions[184] against the already isolated nation.[185] North Korea is the only nation to have withdrawn from the Nuclear Non-Proliferation Treaty,[186] and is the only country to have conducted nuclear tests in the 21st century, starting in 2006, [187] as well as developing a ballistic missile capability.[188] It has also been involved in the export of weapons technology, undermining the Treaty.[189] Diplomatic attempts to deal with North Korea (especially on the part of the United States) have generally been inconsistent and unsuccessful.[190]

Though the situation remains a potential flashpoint for conventional and nuclear conflict, and its collapse could have disastrous consequences[191] (including the possibility of "loose nukes" becoming available to various groups), it should be noted that the "North Korean problem" has existed in one form or another since the end of the Korean War in 1953, without erupting into open conflict.[192]

04-Mar-13: Conference: Humanitarian Impact of Nuclear weapons [193]

– Policy

On 4 and 5 March 2013, the Norwegian Minister of Foreign Affairs, Espen Barth Eide, hosted an international conference on the humanitarian impact of nuclear weapons. The conference heard presentations on the effects of nuclear weapons detonations. Three key points emerged:

– It is unlikely that any state or international body could address the immediate humanitarian emergency caused by a nuclear weapon detonation in an adequate manner and provide sufficient assistance to those affected. Moreover, it might not be possible to establish such capacities at all.
– The historical experience from the use and testing of nuclear weapons has demonstrated their devastating immediate and long-term effects. While political circumstances have changed, the destructive potential of nuclear weapons remains.
– The effects of a nuclear weapon detonation, irrespective of cause, will not be limited by national borders, and will affect states and people to significant degrees, regionally as well as globally.

A number of states wished to explore these issues further, and Mexico said it would host a follow-up conference.[194]

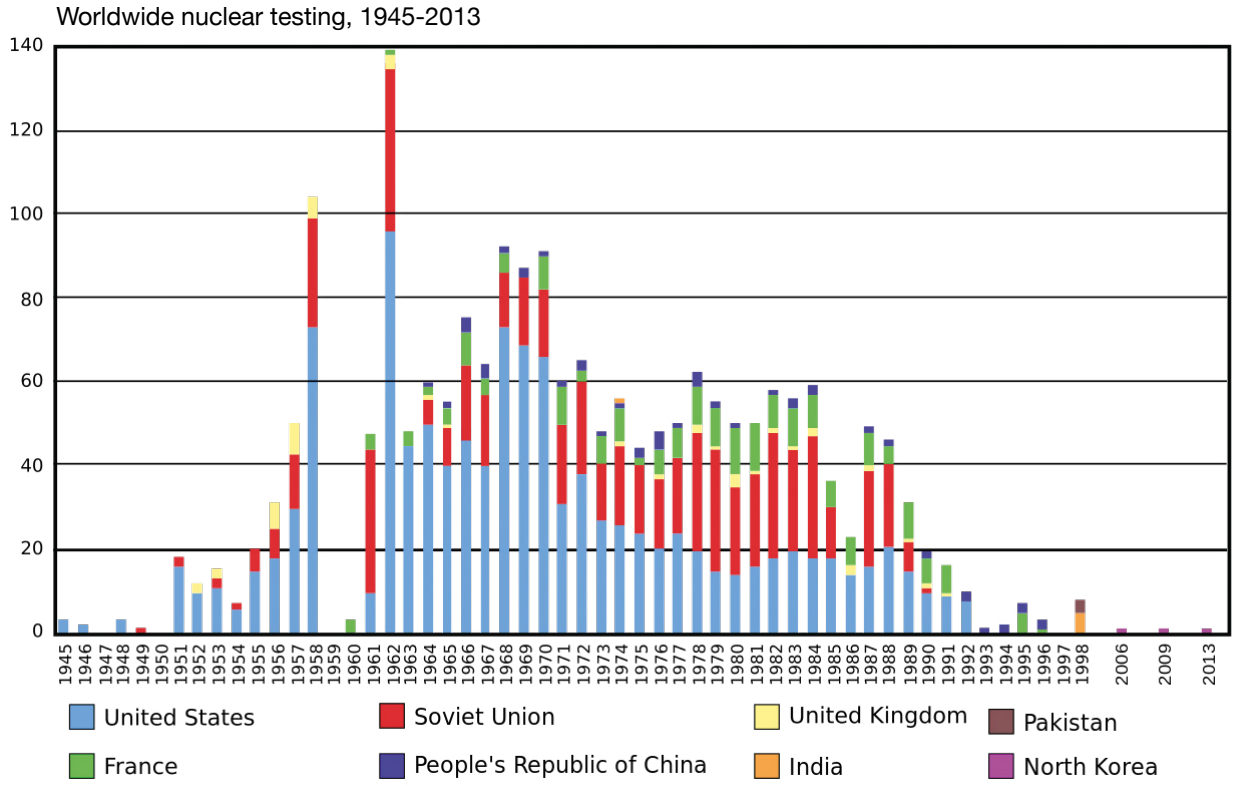


Figure 16, Source: Wikimedia Commons, http://en.wikipedia.org/wiki/File:Worldwide_nuclear_testing.svg CC-BY-SA license.

16-May-13: Revealed: The USSR and US Came Closer to Nuclear War Than Was Thought [195]

– Research

Documents recently released under a FOIA (US Freedom Of Information Act) request show that the risk of nuclear conflict between the superpowers was higher than realised at the time. The large-scale 1983 NATO nuclear exercises Able Archer 83" spurred "a high level of Soviet military activity, with new deployments of weapons and strike forces." This unprecedented Soviet reaction in turn created a series of introspective US intelligence analyses and counter-analyses, debating whether US intelligence had actually understood Soviet actions, perceptions, and fears – and acknowledging the danger of nuclear "miscalculation" if it had not.[196]

This is but one of the many nuclear accidents[197] and incidents that peppered the Cold War and its aftermath, and which have been revealed only subsequently. We know now that there were at least three occasions – the Cuban missile crisis in 1962,[198] the Petrov incident in 1983[199] and the Norwegian rocket incident in 1995[200] – where a full-scale nuclear war was only narrowly averted.[201] Further information on these incidents, and on how they were interpreted and misinterpreted[202] by the great powers, will be important to estimate the probability of nuclear conflict in the coming decades. On a more positive note, efforts are being made to reduce the probability of inadvertent or accidental nuclear conflicts.[203]

24-Jun-13: Report: "Analysing and Reducing the Risks of Inadvertent Nuclear War Between the United States and Russia" [204]

– Research

Though the end of the Cold War has reduced the likelihood of deliberate nuclear war, its impact on the risk of accidental nuclear war is much smaller. The arsenals remain on "launch on warning",[205] meaning that there is a possibility for a "retaliatory" strike before an attack is confirmed. The most likely cause of such an accident is either a false warning (of which there have been many, with causes ranging from weather phenomena to a faulty computer chip, wild animal activity, and control-room training tapes loaded at the wrong time)[206] or a misinterpreted terrorist attack.[207]

The report attempted a rigorous estimate of the numerical probability of nuclear war. Such numerical rigour is rare, with the exception of Hellman's estimates.[208] This report applied risk analysis methods using fault trees and mathematical modelling to assess the relative risks of multiple inadvertent nuclear war scenarios previously identified in the literature.

Then it combined the fault tree-based risk models with parameter estimates sourced from the academic literature, characterising uncertainties in the form of probability distributions, with propagation of uncertainties in the fault tree using Monte Carlo simulation methods. Finally, it also performed sensitivity analyses to identify dominant risks under various assumptions. This kind of highly disaggregated analysis is most likely to elicit the best performance and estimates from experts.[209]

Their conclusion was that (under the more pessimistic assumption), there was a mean 2% risk of accidental nuclear war a year (a high risk when compounded over several decades), with the risk from false alarm being orders of magnitude higher than that from terrorist attacks. The analysis suggests that the most important inadvertent nuclear war risk factor is the short launch decision times,[210] inherent in the "launch on warning" posture. Some ways of improving this were suggested, for instance by moving each country's strategic submarines away from the other's coasts.

03-Sep-13: Report of the UN General Assembly working group on "Taking Forward Multilateral Nuclear Disarmament Negotiations" [211]

– Policy

The working group had extensive exchanges of view from different participants, and reviewed existing disarmament commitments and proposals, including international law. The issues surrounding disarmament and treaties were analysed in depth, and several proposals were put forward, with an eye to the complete elimination of nuclear weapons.

A key recognition was, however, that "participants recognised the absence of concrete outcomes of multilateral nuclear disarmament negotiations within the United Nations framework for more than a decade". Indeed, though the Nuclear Non-Proliferation Treaty[212] (NPT) is a multilateral treaty closely connected with the United Nations, and though it committed the nuclear powers to reduce their arsenals, all the major nuclear arms reduction deals have been bilateral treaties between the US and the USSR/Russia. These include the INF treaty[213], START I[214], SORT[215], and New START[216], which have significantly reduced the world's stock of nuclear weapons. It has also been argued that the NPT has been undermined by a number of bilateral deals made by NPT signatories, most notably the United States.[217] This further serves to emphasise the weakness of international institutions where nuclear arms control is concerned.

15-Nov-13: International Physicians for the Prevention of Nuclear War report: "Nuclear Famine: Two Billion People at Risk?" [218]

– Research

This report is one of a series of reports and publications in recent years about the potential impacts of nuclear conflicts.[219] It looked at the likely consequences of a "limited" nuclear war, such as between India and Pakistan.

While previous papers had estimated that up to a billion people might be at risk in such a conflict,[220] this report increased the estimate to two billion. The main source of this increase is decreased agricultural production in the United States[221] and in China.[222] A key component of these estimates was the severe agricultural impact of the relatively mild temperature reduction in 1816, the "year without a summer" [223], due mainly to the "volcanic winter" caused by the eruption of Mount Tambora. The report highlights some significant areas of uncertainty, such as whether a small nuclear conflict and its consequences would lead to further conflicts across the world, and doubts whether markets, governments and other organisations could mitigate the negative impacts. The report is a reminder that even small-scale nuclear conflict could have severe consequences.

24-Nov-13: Nuclear deal with Iran may reduce risk of proliferation [224]

– Policy

In November, Iran struck a deal with the so called "P5+1" (the five permanent members of the security council, plus Germany). The deal, if it holds, would allow Iran to continue some uranium enrichment, but it would have to submit to inspections to ensure it wasn't developing a nuclear weapons programme (the deal would also result in eased sanctions in return). There have been long-running fears than Iran may have been attempting to construct a nuclear weapon[225], resulting in sanctions being imposed on it.[226]

This event illustrates the surprising success of the Non-Proliferation Treaty,[227] which came into force in 1970. At the time it was proposed there were fears of very rapid proliferation of nuclear weapons.[228] And though 40 countries or more currently have the knowhow to build nuclear weapons,[229] only nine countries are currently known to possess them: the five security council members, India, Pakistan, and North Korea, plus Israel.[230]

3.1 Current risk

3.1.3 Ecological Catastrophe

Ecological collapse refers to a situation where an ecosystem suffers a drastic, possibly permanent, reduction in carrying capacity for all organisms, often resulting in mass extinction.

Usually an ecological collapse is precipitated by a disastrous event occurring on a short time scale. [231]

3.1.3.1 Expected impact

Humans are part of the global ecosystem and so fundamentally depend on it for our welfare.

Species extinction is proceeding at a greatly increased rate compared with historic data[232], and attempts to quantify a safe ecological operating space place humanity well outside it.[233] Furthermore, there may be signs of a "sudden" biosphere collapse, possibly within a few generations.[234] Many of the problems of ecological degradation interact to multiply the damage and (unlike previous, localised collapses) the whole world is potentially at risk, [235] with severe challenges to countering this risk through global policy.[236]

If animals are seen to have intrinsic value, [237] or if human quality of life is dependent on a functioning ecosystem, [238] the current situation already represents a large loss.

Whether such a loss will extend to human lives depends on technological and political factors - technological, because it seems plausible that some human lifestyles could be sustained in a relatively ecosystem-independent way, at relatively low costs.[239] Whether this can be implemented on a large scale in practice, especially during a collapse, will be a political challenge and whether it is something we want is an ethical question.

There is currently more than enough food for everyone on the planet to ensure the nutrition needed, [240] but its distribution is extremely uneven and malnutrition persists. Thus ecological collapse need not have a strong absolute effect in order to result in strong localised, or global, effects. Even a partial collapse could lead to wars, mass migrations, and social instability. It is conceivable that such a scenario, if drawn out and exacerbated by poor decision-making, could eventually lead to mass deaths and even the collapse of civilisation.

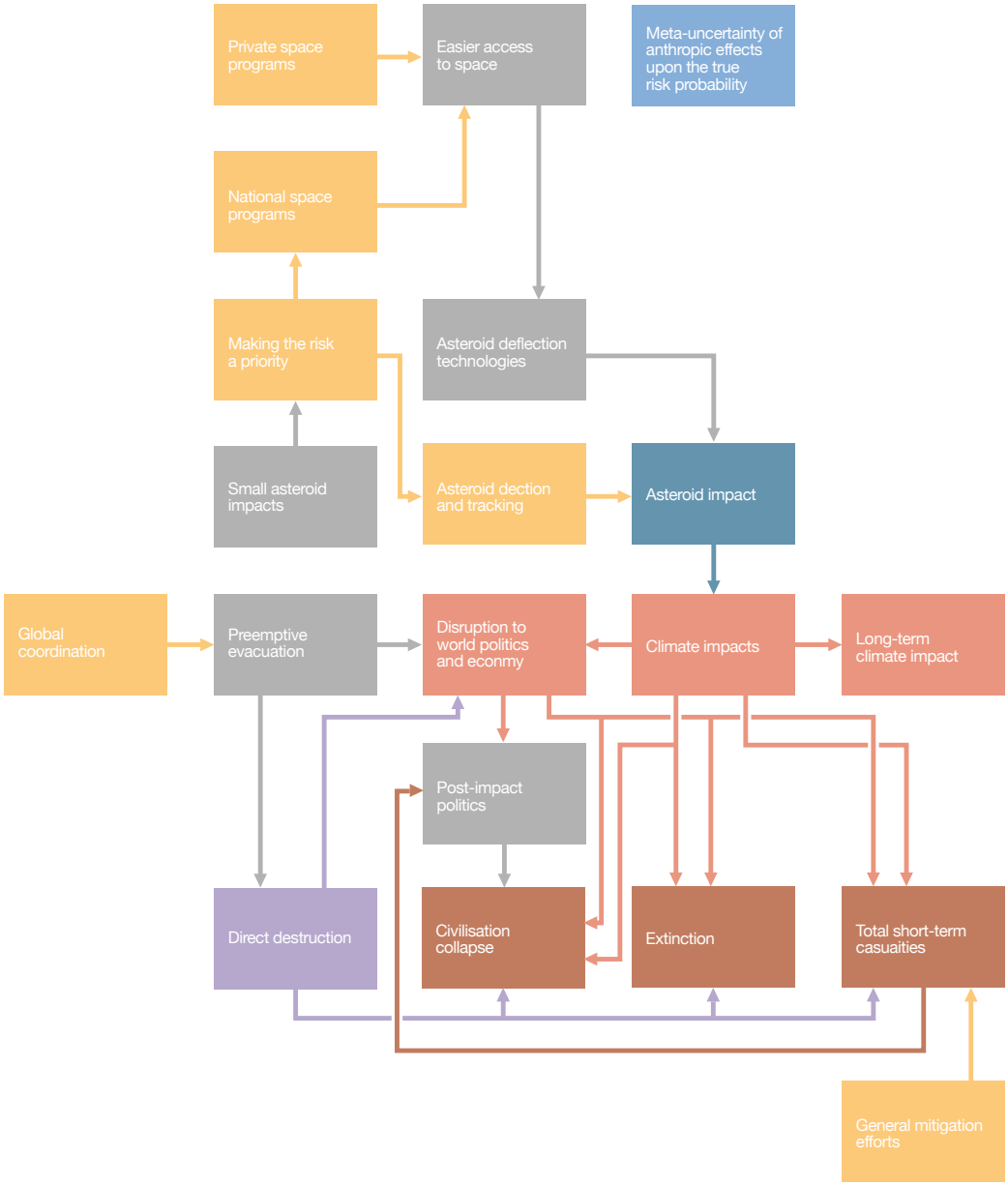
Extinction risk is possible only if the aftermath of collapse fragments and diminishes human society so far that recovery becomes impossible[241] before humanity succumbs to other risks (such as climate change or pandemics).

After a post-civilisation collapse human society could still be suffering from the effects of ecological collapse, depending on what form it took, this could make the recovery of human civilisation more challenging than in some of the other scenarios presented here.

3.1.3.2 Probability disaggregation

Five important factors in estimating the probabilities and impacts of the challenge:

1. The extent to which humans are dependent on the ecosystem.
2. Whether there will be effective political measures taken to protect the ecosystem on a large scale.
3. The likelihood of the emergence of sustainable economies.
4. The positive and negative impacts on the eco systems of both wealth and poverty.
5. The long-term effects of an ecological collapse on ecosystems.



Key

Uncertain events | Meta-uncertainties | Risk events | Direct impacts | Indirect impacts | Current intervention areas | Bad decisions | Accidents | Severe impacts

1. Global coordination and cooperation will be important to any attempt to control ecological damage on a large scale and prevent "races to the bottom".

2. Poverty is often seen as exacerbating ecological damage through unsustainable practices, while richer countries introduce environmental regulations – but richer nations exploit many resources (such as fossil fuels) in non-sustainable and damaging ways.

3. Transitioning to sustainable economies, or sustainable economic trajectories, could control ecological damage.

4. Research into sustainability could allow the construction of sustainable economies or environments at costs that people are willing to bear.

5. Climate change exacerbates the pressure on the ecological system by changing weather patterns and increasing natural disasters in ways ecosystems find hard to adapt to.

6. Global pollution is a visible source of ecological damage, one that global agreements have had moderate success at tackling.

7. Truly global preservation efforts may be needed for some threatened ecosystems that stretch beyond natural boundaries (e.g. in the seas and oceans).

8. Beyond general all-purpose mitigation efforts, addressing this threat could include the preservation of ecosystems, species or genetic codes, to allow a subsequent rebuilding.

9. New, profitable, but environmentally damaging industries could put extra strain on the ecosystem.

10. According to some systems of value, the loss of certain animals and ecosystems constitutes a moral tragedy in and of itself.

11. Humans derive much pleasure and many benefits from various parts of the ecosystem, and losing this would result in a loss to human quality of life.

12. Ongoing and continuous biodiversity loss is a clear consequence of ecological collapse.

13. Ecological damage can put the human food system in danger, triggering famines.

14. Ecological damage increases vulnerability to floods and other natural disasters.

15. Disruptions to the world's political and economic systems could trigger further conflicts or instabilities, causing more casualties and impairing effective response.

16. Since a lot of the world's carbon is locked up in trees, ecological collapse could exacerbate climate change.

17. The ecosystem is of great economic benefit to humanity, so its loss would have large economic costs.

18. Ecological damage is likely to be long-term: the effects will last for many generations.

19. Technological innovations may result in more sustainable economies, or in more environmentally damaging products.

20. It may be possible to ensure human survival in semi-"closed" systems (solar power, hydroponic food, distilled water), with minimal dependency on the external ecosystem.

21. Over the long term, it may become possible and necessary to go about rebuilding the ecosystem and healing its damage.

22. Political decisions will be the most likely factors to exacerbate or mitigate an ecological disaster.

23. It is unclear how dependent humans truly are on the ecosystem, and how much damage they could inflict without threatening their own survival.

3.1.3.3 Main events during 2013

22-Jan-13: Current extinctions probably the result of past actions; many future extinctions to come [242]
– Research

An estimated 40% of world trade is based on biological products or processes such as agriculture, forestry, fisheries and plant-derived pharmaceuticals, and biodiversity comprises an invaluable pool for innovations.[243] And yet this biodiversity is being lost at an alarming rate – the rate of extinctions for plants and animals is 100 to 1,000 times higher than their pre-human levels.[244] A variety of methods have been suggested to halt or slow this loss, ranging from putting an explicit value[245] on biodiversity and ecosystem services (human benefits from a multitude of resources and processes that are supplied by ecosystems), [246] to performing triage on the most valuable species.[247] This research paper suggests, however, that there is a lag of several decades between human pressure on the ecosystem and ultimate species extinction. This suggests that many extinctions will continue in decades to come, irrespective of current conservation efforts.

05-Apr-13: Ocean data added to Microsoft Eye on Earth project
– Initiative

In order to safeguard ecological resources, it is important to track and quantify them. This has traditionally been the role of governments or non-governmental organisations.[248] Recently, however, private organisations have started developing tools to enable companies and individuals to track ecological damage and make decisions in consequence. One such tool was Eye on Earth, developed by Microsoft in alliance with the European Environment Agency and Esri.[249] It was launched with three services – WaterWatch, AirWatch and NoiseWatch – keeping track of the levels of different pollutants, using official sources and inputs from citizens.[250] This was subsequently expanded to include other environmentally sensitive pieces of information, such as the states of coral reefs and invasive alien species.

It was primarily land-based, so the oceans were missing from this visualisation tool. This lack has been partially overcome with the inclusion of data from the MyOcean 2 project[251] (partly funded by the European Commission). The data cover sea surface temperature, salinity and currents for the Mediterranean Sea and the Black Sea.

30-May-13: Improvement in managed fisheries in Europe [252]
– Research

Human action has been shown to be able to mitigate some ecosystem damage. Overfishing is expected by standard economic theory: the sea's resources are a (global) common, where the rational behaviour of individual fishermen must lead to dilapidation of the resource.[253] Unlike on land, where nature reserves or parks can be established, there are no easy ways of establishing property rights in the sea[254] (thus privatising that "common"). A typical example of this behaviour is the collapse of the Grand Banks fisheries off Canada's Atlantic coast in the 1990s, where cod biomass fell by over 95% from its peak and has currently not recovered.[255]

It is therefore significant that the European Union has been partly successful in its attempts to control over-fishing through legislation. For instance, despite the fact that North Sea cod remains vulnerable, there has been a recent increase in stock size and a decrease in fish mortality. This may point to the potential for further ecological improvements through well-chosen policy interventions.

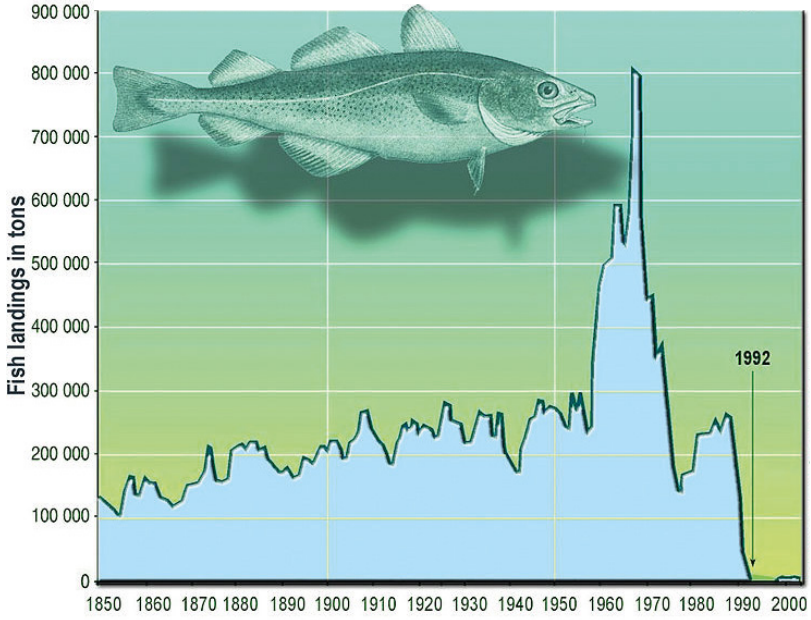


Figure 17: Collapse of Atlantic cod stocks (East Coast of Newfoundland), 1992
Source: http://en.wikipedia.org/wiki/File:Surexploitation_morue_surp%C3%AAcheEn.jpg)

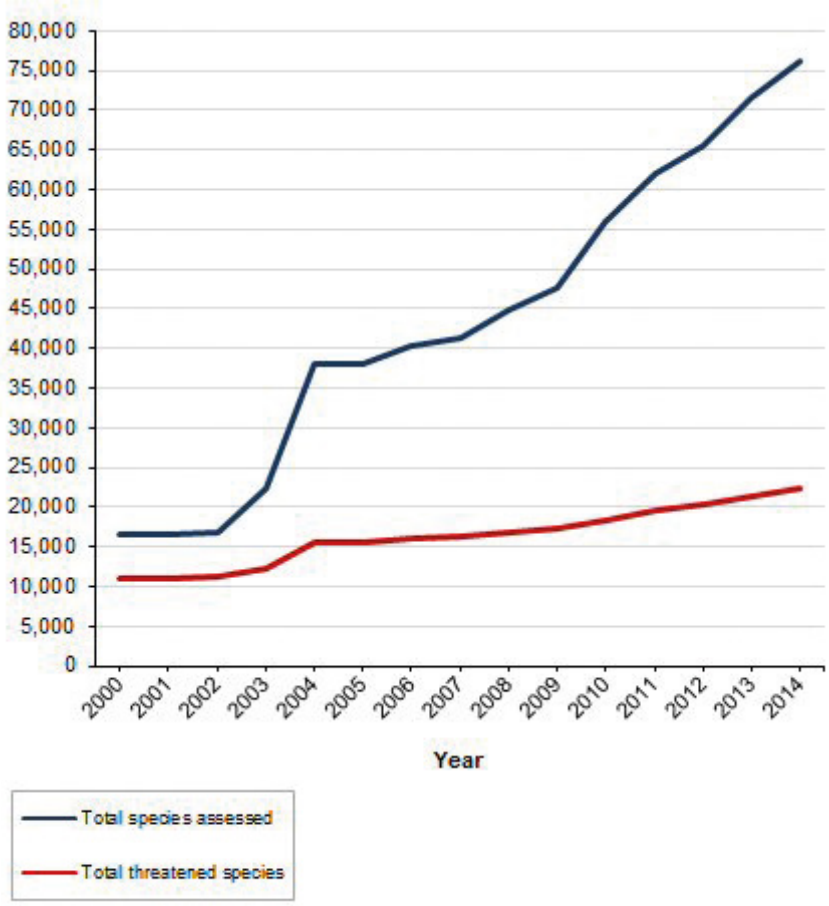


Figure 18: Increase in the number of species assessed for the IUCN Red List of Threatened SpeciesTM (2000–2013.2).
Source: http://www.iucnredlist.org/about/summary-statistics

02-Jul-13: About 21,000 Species Face Extinction, says International Union for Conservation of Nature (IUCN) [256] – Event

In 2013 the IUCN added an additional 4,807 species to its Red List of Threatened Species. This brings the total to about 21,000. Some have argued that we are entering a new geological era in Earth's history: the Anthropocene[257], when human actions are one of the major impactors on the planet's biosphere.

The graph shows a fairly steady growth in the (estimated) number of threatened species. This steadiness may be illusory, as the biosphere shows signs that it may be approaching a planetary-scale tipping point, where it may shift abruptly and irreversibly from one state to another. As a result, the biological resources humans presently take for granted may be subject to rapid and unpredictable transformations within a few human generations.[258] This could be seen as a great tragedy beyond purely human concerns, if animals (and animal welfare) are seen to have intrinsic value.[259]

3.1 Current risk

3.1.4 Global Pandemic

A pandemic (from Greek πᾶν, pan, "all", and δῆμος demos, "people") is an epidemic of infectious disease that has spread through human populations across a large region; for instance several continents, or even worldwide.

Here only worldwide events are included. A widespread endemic disease that is stable in terms of how many people become sick from it is not a pandemic. [260]

3.1.4.1 Expected impact

Infectious diseases have been one of the greatest causes of mortality in history. Unlike many other global challenges pandemics have happened recently, as we can see where reasonably good data exist. Plotting historic epidemic fatalities on a log scale reveals that these tend to follow a power law; with a small exponent: many plagues have been found to follow a power law with exponent 0.26.[261]

These kinds of power laws are heavy-tailed[262] to a significant degree.[263] In consequence most of the fatalities are accounted for by the top few events.[264] If this law holds for future pandemics as well,[265] then the majority of people who will die from epidemics will likely die from the single largest pandemic.

Most epidemic fatalities follow a power law, with some extreme events – such as the Black Death and Spanish 'Flu – being even more deadly.[267]

There are other grounds for suspecting that such a high-impact epidemic will have a greater probability than usually assumed. All the features of an extremely devastating disease already exist in nature: essentially incurable (Ebola[268]), nearly always fatal (rabies[269]), extremely infectious (common cold[270]), and long incubation periods (HIV[271]). If a pathogen were to emerge that somehow combined these features (and influenza has demonstrated antigenic shift, the ability to combine features from different viruses[272]), its death toll would be extreme.

Many relevant features of the world have changed considerably, making past comparisons problematic. The modern world has better sanitation and medical research, as well as national and supra-national institutions dedicated to combating diseases. Private insurers are also interested in modelling pandemic risks.[273] Set against this is the fact that modern transport and dense human population allow infections to spread much more rapidly[274], and there is the potential for urban slums to serve as breeding grounds for disease.[275]

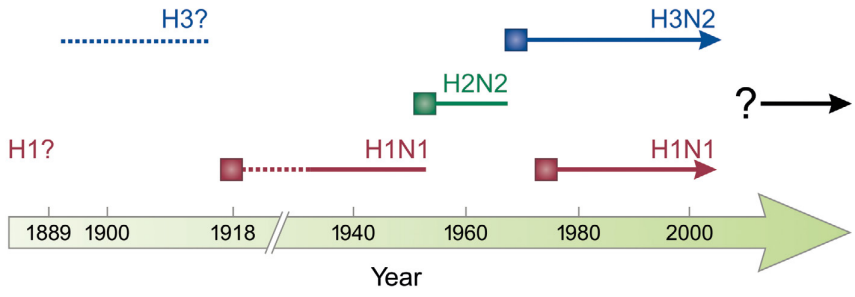
Unlike events such as nuclear wars, pandemics would not damage the world's infrastructure, and initial survivors would likely be resistant to the infection. And there would probably be survivors, if only in isolated locations. Hence the risk of a civilisation collapse would come from the ripple effect of the fatalities and the policy responses. These would include political and agricultural disruption as well as economic dislocation and damage to the world's trade network (including the food trade).

Extinction risk is only possible if the aftermath of the epidemic fragments and diminishes human society to the extent that recovery becomes impossible[277] before humanity succumbs to other risks (such as climate change or further pandemics).

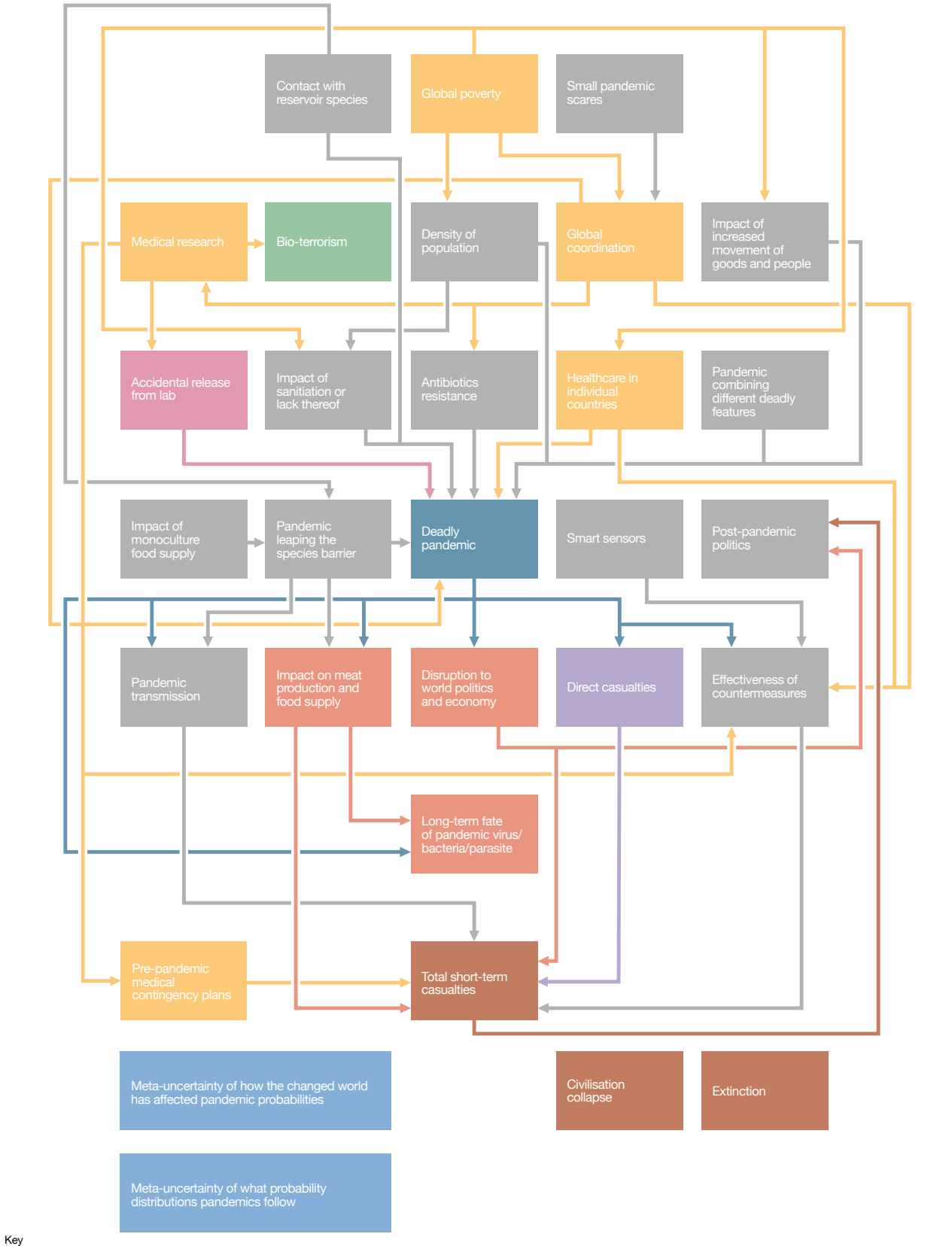
3.1.4.2 Probability disaggregation

Five important factors in estimating the probabilities and impacts of the challenge:

1. What the true probability distribution for pandemics is, especially at the tail.
2. The capacity of modern i international health systems to deal with an extreme pandemic.
3. How fast medical research can proceed in an emergency.
4. How mobility of goods and people, as well as population density, will affect pandemic transmission.
5. Whether humans can develop novel and effective anti-pandemic solutions.



Influenza subtypes[266]


Contact with reservoir species
Global poverty
Small pandemic scares
Medical research
Bio-terrorism
Density of population
Global coordination
Impact of increased movement of goods and people
Accidental release from lab
Impact of sanitiation or lack thereof
Antibiotics resistance
Healthcare in individual countries
Pandemic combining different deadly features
Impact of monoculture food supply
Pandemic leaping the species barrier
Deadly pandemic
Smart sensors
Post-pandemic politics
Pandemic transmission
Impact on meat production and food supply
Disruption to world politics and economy
Direct casualties
Effectiveness of countermeasures
Long-term fate of pandemic virus/ bacteria/parasite
Pre-pandemic medical contingency plans
Total short-term casualties
Meta-uncertainty of how the changed world has affected pandemic probabilities
Civilisation collapse
Extinction
Meta-uncertainty of what probability distributions pandemics follow
Key
Uncertain events
Meta-uncertainties
Risk events
Direct impacts
Indirect impacts
Current intervention areas
Bad decisions
Accidents
Severe impacts

1. Extensive medical research will be key to preventing and combatting large scale pandemics. The drawbacks are the possibility of accidental release of dangerous pathogens from laboratories and of bioterrorism.

2. As so much is known about pandemic risks compared with other risks, there are more possibilities for specific pre-pandemic contingency plans.

3. The effectiveness of healthcare systems will be important, especially in less developed nations where the pandemic may overwhelm the system, and then transmit from there to other nations.

4. Global coordination in detection, analysis and treatment are vital for stopping a pandemic in its early stages, and for implementing measures such as quarantines and more advanced countermeasures.

5. Poverty will affect the quality of national healthcare systems, population density and sanitation quality, the movement of local goods and people, and the effectiveness of the political response.

6. Bioterrorists may unleash a pathogen held in storage, such as smallpox.

7. Laboratory security at the top labs is insufficient for the danger at hand, and accidental release is a non-negligible possibility.

8. Pandemics are one of the risks where there is a possibility for a very large number of direct casualties, depending on the severity of the pathogen.

9. Mass casualties and finger-pointing could destabilise the world political and economic systems.

10. If the pathogen is transmissible to farm animals, this could affect the world food supply.

11. It is unlikely the pathogen would be a recurrent, long-term risk, but variants of it could continue to affect people and animals for many years, dependent on its transmissibility and life cycle.

12. Small pandemic scares could improve global coordination on the issue.

13. Increased population density causes increased transmissibility of the pathogen, especially in urban slums.

14. Some pathogens, such as bird 'flu, depend on regular contact between humans and "reservoir species" in order to evolve into periodically dangerous strains.

15. If antibiotic resistance develops, humanity could see the resurgence of bacteria-based pandemics.

16. The increased movement of people and products increases the speed and spread of pandemic transmission.

17. Sanitation or its lack will strongly affect the spread of certain pathogens in key areas.

18. The efficiency of global reaction to a new pandemic will be strongly determined by the speed of research on the pathogen during the pandemic.

19. A great risk will arise if a pathogen combines the different dangerous features of current viruses or bacteria.

20. The improvements to surveillance and sensing technologies (including indirect detection via web queries or social media) open the possibility of smarter interventions (such as micro-quarantines) and faster understanding of the pathogen's transmissibility.

21. Post-pandemic politics will be important for preventing a civilisation collapse or enabling reconstruction.

22. Many pathogens incubate in species close to humans, before leaping the species barrier.

23. Monoculture food systems make it easier to transmit any pathogen infecting human food animals.

24. The mode of transmission of the pathogen will be critical to its ultimate reach and impact.

25. Various countermeasures are available in terms of detection, virus analysis, treatment, and quarantining. Future research, technological and political developments may open up new methods of fighting the pathogen.

26. Many of the current factors determining pathogen transmission are unprecedented, such as movements of goods and people, the quality of healthcare systems, and the existence of a centralised political response. This means that data from past pandemics will not be as reliable for computing probability distributions.

27. The pandemic risk lies in the "tails" – the extreme events – and these tails must be estimated from few data points, making them tricky and uncertain.

3.1.4.3 Main events during 2013

10-Jun-13: Pandemic Influenza Risk Management: WHO Interim Guidance [278]

– Policy

This is an updated document that replaces the 2009 Pandemic Influenza Preparedness and Response: a WHO guidance document.[279] It updates its recommendations based on lessons from the influenza A(H1N1) 2009 pandemic (swine 'flu),[280] the adoption by the Sixty-fourth World Health Assembly of the Pandemic Influenza Preparedness Framework[281] (for the sharing of influenza viruses and access to vaccines and other benefits), and the States Parties' obligations on capacity strengthening contained in the International Health Regulations of 2005.[282]

Of significance was the Report of the Review Committee on the Functioning of the International Health Regulations (2005) on the A(H1N1) 2009 pandemic,[283] which concluded: "We were lucky this time, but as the report concludes, the world is ill-prepared to respond to a severe influenza pandemic or to any similarly global, sustained and threatening public-health emergency." This is reinforced by the fact that the 2009 pandemic is alleged to have infected 24% of the population.[284]

The main lesson the WHO drew from that epidemic was that member states generally had communication issues (between ministries of health and decision,makers, and with the public), and were prepared for a pandemic of high severity and appeared unable to adapt their national and subnational responses adequately to a more moderate event.

The guidance paper indicates simultaneously the weaknesses of pandemic preparations, the improvements in these preparations, and the continued role of the WHO as global directing and coordinating authority.

24-Jul-13: Bacteria become resistant to some of the last remaining antibiotics [285]

– Event

Bacterial infections, such as the Black Death, [286] syphilis, [287] and tuberculosis, [288] have been responsible for millions of deaths, over the thousands of years they have co-existed with humanity. Though these diseases have not been eradicated – overall, a third of the world is currently infected with the tuberculosis bacillus[289] – they have been controlled since the introduction of antibiotics, and prognostics have improved tremendously. But recently a rising number of bacteria have developed antibiotic resistance, due mainly to antibiotic over-prescription[290] and use in livestock feed.[291] This Nature report highlights the worrying way in which Enterobacteriaceae (bacteria with a 50% mortality rate) have become resistant to carbapenems, one of the last remaining antibiotics that had been effective against them.

09-Aug-13: Epihack: Digital disease surveillance hack-a-thon [292]

– Initiative

Beyond the formal, top-down initiatives to deal with pandemics, there are openings for bottom-up, innovative ideas. Epihack attempted to generate just such ideas, through three days of designing and hacking in Cambodia. Descriptions of the winning projects were given:

– CoPanFlu This project included home visits to collect blood samples from 807 homes and weekly follow-up phone calls to document the occurrence of infectious respiratory symptoms. These visits and phone calls caused disturbance to the participants. The new system uses SMS for users to report symptoms. Chart and map visualisation of the data (with full case details) and a fieldwork tracking tool were developed to help the research team analyse and monitor data.

– DoctorMe In addition to all of the popular features of DoctorMe (free health information for the general public), the tool now features a weekly survey for users. The survey will ask participants to select whether they are experiencing any symptoms from a list.

– ILI Surveillance, Bureau of Epidemiology Thailand The old system was web-based and had no visual element. The new mobile application and website provide a map visualisation for the reported cases of influenza-like illness (ILI) in Thailand. The map shows hospital ILI cases with colour-coded pins to indicate the level of ILI and allows for simple analysis of the situation.

– Mae Tao Clinic The electronic records for this healthcare clinic were very basic. During EpiHack, the data was moved to the cloud and is now open-source. A data visualisation dashboard was created to allow for map visualisation of diagnoses. The staff at Mae Tao Clinic can now easily view and analyse the data to spot trends and send alerts. They plan to pilot this programme at their clinic and, if successful, to replicate it with other clinics.

– Verboice The technology platform of Verboice is so user-friendly it doesn't require technical developers to develop the systems. At EpiHack, project managers were able to design and create systems to address needs in their work completely on their own. In just eight hours, four project managers each completed their own voice-based participatory surveillance systems to monitor One Health in Kenya and Tanzania; early warning generation in South Sudan; animal health in Laos; unexploded ordnance in Laos; child trafficking in Cambodia. The project owners of these new systems will now take them back to their countries and develop implementation and sustainability plans.

22-Sep-13: Research hints at possibility for universal 'flu vaccine [293]

– Research

The Spanish 'flu outbreak was the deadliest short pandemic in history, infecting about a third of the world population (≈ 500 million people) and killing 50-100 million people.[294] There have been numerous 'flu pandemics in the last few centuries, with three others having around a million casualties (the 1889-1890 Russian 'Flu,[295] the 1957-1958 Asian 'Flu, and the 1968-1969 Hong Kong 'Flu[296] outbreaks). The most recent pandemic was that in 2009, which killed 150,000-500.000 people.[297] Thus any move towards a universal 'flu vaccine would be of great importance to combating such recurring pandemics. This paper, analysing the role of T cells in combating influenza, suggests a way that such a vaccine could be feasible.

28-Nov-13: Difficulties in containing the accidental laboratory escape of potential pandemic influenza viruses [298]

– Research

Biosafety laboratories experiment with some of the deadliest of the world's pathogens, and occasionally create new ones.[299] Their number is increasing globally, and their safety record is far from perfect, with several pathogen leaks reported[300] and others suspected[301] (the last smallpox fatality was due to a virus that escaped a lab[302], after eradication of the virus in the wild). The rate of pathogen escape has been estimated at 0.3% per laboratory, per year[303] – a very high probability, given the 44 BSL-4[304] labs and several thousands of BSL-3 labs. There have already been three known escapes from BSL-4 labs since 1990.[305]

This report uses an agent-based model to analyse whether the accidental laboratory release of pandemic 'flu viruses could be contained, and concludes that controllability of escape events is not guaranteed.

3-Dec-13: Global pandemic tops poll of insurance industry risks [306]

– Initiative

Academics and governmental[307]/ supra-governmental[308] organisations have long worried about the risks of pandemics. But such organisations attract certain types of people with specific outlooks, who can be subject to further biases because of their profession and the social milieu surrounding it.[309] Insurers come from a different background, focusing on practical profitability in the business world. It is therefore instructive that they too see pandemics as among the major threats in the world today. This also implies that combatting pandemics is of use not only from a humanitarian but also from an economic standpoint.

3.1 Current risk

3.1.5 Global System Collapse

Global system collapse is defined here as either an economic or societal collapse on the global scale. There is no precise definition of a system collapse. The term has been used to describe a broad range of bad economic conditions, ranging from a severe, prolonged depression with high bankruptcy rates and high unemployment, to a breakdown in normal commerce caused by hyperinflation, or even an economically-caused sharp increase in the death rate and perhaps even a decline in population. [310]

Often economic collapse is accompanied by social chaos, civil unrest and sometimes a breakdown of law and order. Societal collapse usually refers to the fall or disintegration of human societies, often along with their life support systems. It broadly includes both quite abrupt societal failures typified by collapses, and more extended gradual declines of superpowers. Here only the former is included.

3.1.5.1 Expected impact

The world economic and political system is made up of many actors with many objectives and many links between them. Such intricate, interconnected systems are subject to unexpected system-wide failures due to the structure of the network[311] – even if each component of the network is reliable. This gives rise to systemic risk: systemic risk occurs when parts that individually may function well become vulnerable when connected as a system to a self-reinforcing joint risk that can spread from part to part (contagion), potentially affecting the entire system and possibly spilling over to related outside systems.[312] Such effects have been observed in such diverse areas as ecology,[313] finance[314] and critical infrastructure[315] (such as power grids). They are characterised by the possibility that a small internal or external disruption could cause a highly non-linear effect,[316] including a cascading failure that infects the whole system,[317] as in the 2008-2009 financial crisis.

The possibility of collapse becomes more acute when several independent networks depend on each other, as is increasingly the case (water supply, transport, fuel and power stations are strongly coupled, for instance).[318] This dependence links social and technological systems as well.[319]

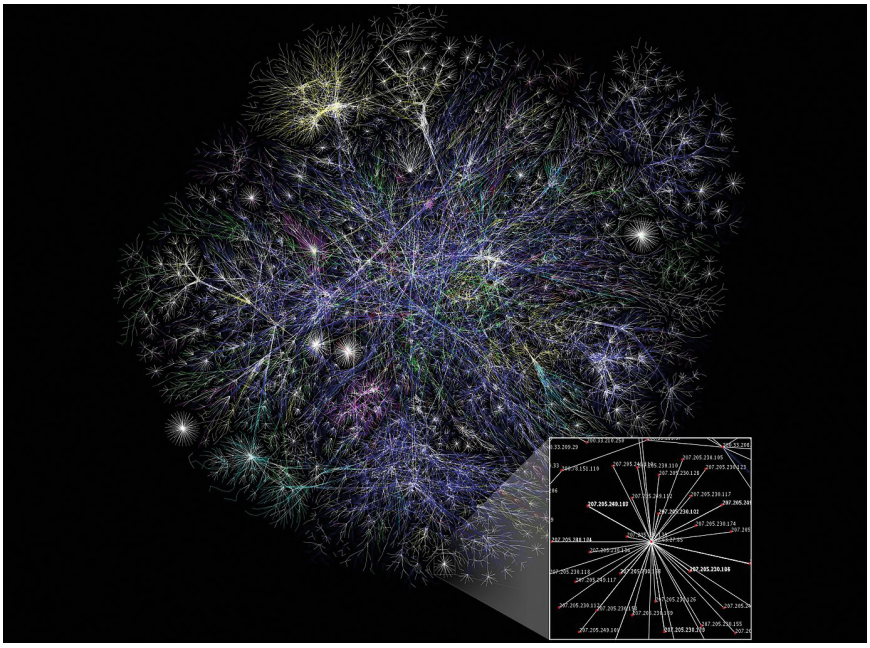
This trend is likely to be intensified by continuing globalisation,[320] while global governance and regulatory mechanisms seem inadequate to address the issue.[321] This is possibly because the tension between resilience and efficiency[322] can even exacerbate the problem.[323]

Many triggers could start such a failure cascade, such as the infrastructure damage wrought by a coronal mass ejection,[324] an ongoing cyber conflict, or a milder form of some of the risks presented in the rest of the paper. Indeed the main risk factor with global systems collapse is as something which may exacerbate some of the other risks in this paper, or as a trigger. But a simple global systems collapse still poses risks on its own. The productivity of modern societies is largely dependent on the careful matching of different types of capital[325] (social, technological, natural...) with each other. If this matching is disrupted, this could trigger a "social collapse" far out of proportion to the initial disruption.[326] States and institutions have collapsed in the past for seemingly minor systemic reasons.[327] And institutional collapses can create knock-on effects, such as the descent of formerly prosperous states to much more impoverished and destabilising entities.[328] Such processes could trigger damage on a large scale if they weaken global political and economic systems to such an extent that secondary effects (such as conflict or starvation) could cause great death and suffering.

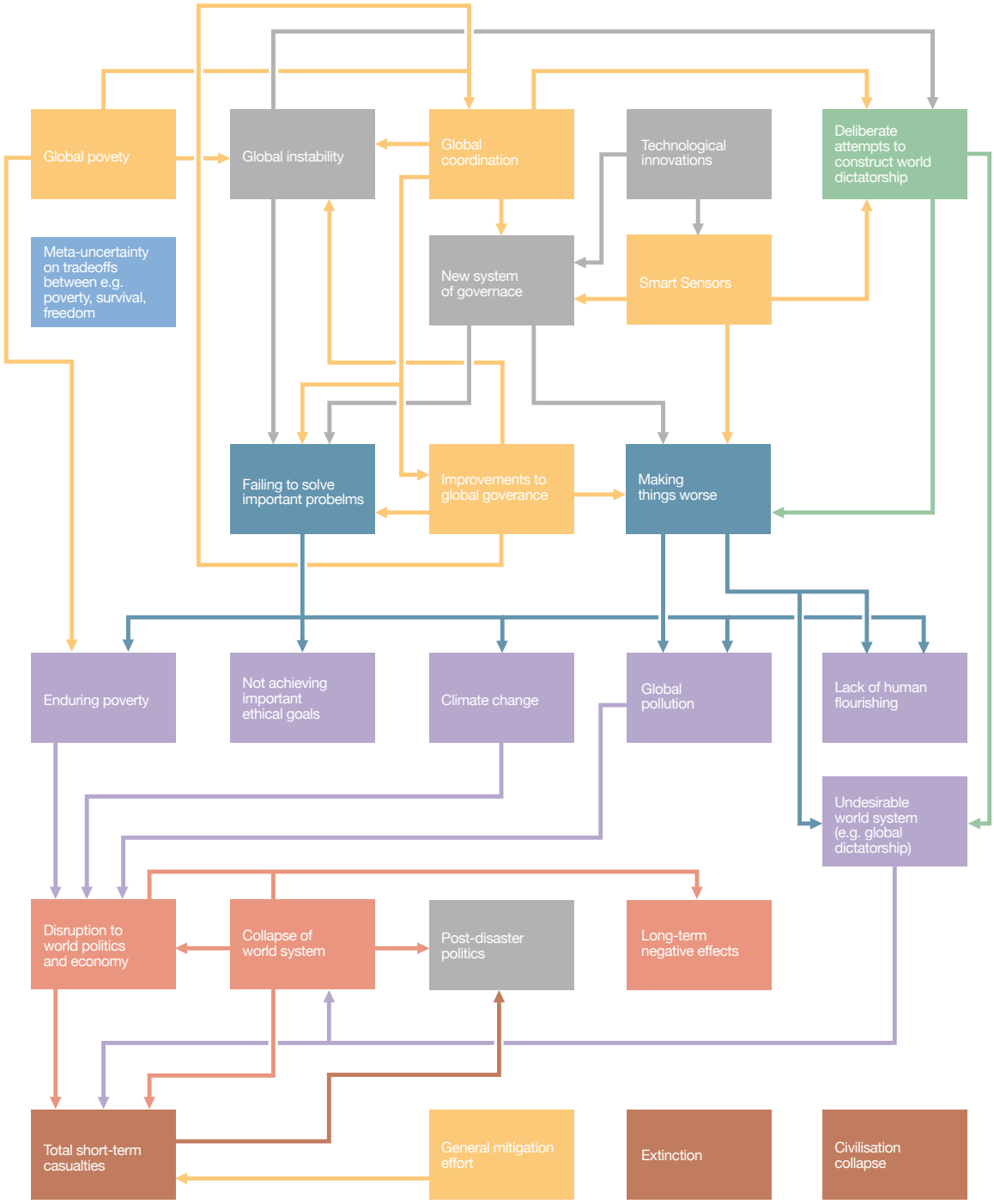
3.1.5.2 Probability disaggregation

Five important factors in estimating the probabilities of various impacts:

1. Whether global system collapse will trigger subsequent collapses or fragility in other areas.
2. What the true trade-off is between efficiency and resilience.
3. Whether effective regulation and resilience can be developed.
4. Whether an external disruption will trigger a collapse.
5. Whether an internal event will trigger a collapse.



Example of an interconnected network: the Internet. Each line is drawn between two nodes, representing two IP addresses. This is a small look at the backbone of the Internet.
Source: http://en.wikipedia.org/wiki/File:Internet_map_1024.jpg



Key

Uncertain events | Meta-uncertainties | Risk events | Direct impacts | Indirect impacts | Current intervention areas | Bad decisions | Accidents | Severe impacts

1. Increased global coordination and cooperation may allow effective regulatory responses, but it also causes the integration of many different aspects of today's world, likely increasing systemic risk.

2. Systemic risk is only gradually becoming understood, and further research is needed, especially when it comes to actually reducing systemic risk.

3. Since systemic risk is risk in the entire system, rather than in any individual component of it, only institutions with overall views and effects can tackle it. But regulating systemic risk is a new and uncertain task.

4. Building resilience – the ability of system components to survive shocks – should reduce systemic risk.

5. Fragile systems are often built because they are more efficient t han robust systems, and hence more profitable.

6. General mitigation efforts should involve features that are disconnected from the standard system, and thus should remain able to continue being of use if the main system collapses

7. A system collapse could spread to other areas, infecting previously untouched systems (as the sub-prime mortgage crisis affected the world financial system, economy, and ultimately its political system).

8. The system collapse may lead to increased fragility in areas that it does not directly damage, making them vulnerable to subsequent shocks.

9. A collapse that spread to government institutions would undermine the possibilities of combating the collapse.

10. A natural ecosystem collapse could be a cause or consequence of a collapse in humanity's institutions.

11. Economic collapse is an obvious and visible way in which system collapse could cause a lot of damage.

12. In order to cause mass casualties, a system collapse would need to cause major disruptions to the world's political and economic system.

13. If the current world system collapses, there is a risk of casualties through loss of trade, poverty, wars and increased fragility.

14. It is not obvious that the world's institutions and systems can be put together again after a collapse; they may be stuck in a suboptimal equilibrium.

15. Power grids are often analysed as possible candidates for system collapse, and they are becoming more integrated.

16. The world's financial systems have already caused a system collapse, and they are still growing more integrated.

17. The world's economies are also getting integrated, spreading recessions across national boundaries.

18. The world's political and legal systems are becoming more closely integrated as well. Any risk has not been extensively researched yet, and there remain strong obstacles (mainly at the nation state level) slowing down this form of integration.

19. The politics of the post-system collapse world will be important in formulating an effective response instead of an indifferent or counter-productive one.

20. System collapses can be triggered internally by very small events, without an apparent cause.

21. External disruptions can trigger the collapse of an already fragile system.

22. The trade-off between efficiency and resilience is a key source of fragility, in a world economy built around maximising efficiency.

23. Climate change, mass movements of animals and agricultural mono-cultures are interlinking ecosystems with each other and with human institutions.

24. There is a lot of uncertainty about systemic risk, especially in the interactions between different fragilities that would not be sufficient to cause a collapse on their own.

3.1.5.3 Main events during 2013

16-Jan-13: Systemic Risk Centre founded at the LSE [329]

– Event

Effective interventions into systemic risks depend on high quality research, which may be why the London School of Economics (LSE) founded a £5 million research centre to study systemic financial risk. A press release said:

"The Centre will undertake an economic analysis of the fundamental risks to the financial system, based on an interdisciplinary approach. It will bring together experts from finance, economics, computer science, political science, law and the natural and mathematical sciences. This will allow researchers affiliated to the Centre to investigate how risk is created through feedback loops within and between the financial, economic, legal and political systems. Political decisions, for example, can directly affect people's behaviour in the financial markets, which in turn affects political decision-making and so on – with the outcomes being unexpected and complex."

Besides the research results produced by the centre, its very existence shows that systemic risk is being taken seriously in academic quarters.

14-Mar-13: Systemic sovereign credit risk has "deep roots in the flows and liquidity of financial markets." [330]

– Research

It is important to estimate the source of systemic risk. Different mitigation policies should be implemented if sovereign systemic risks spring from financial markets rather than macroeconomic fundamentals. This paper argues that systemic sovereign risks spring from financial markets (through capital flows, funding availability, risk premiums, and liquidity shocks[331]) rather than from fundamentals.[332] It further estimates that systemic risks are three times larger in eurozone countries than in US states.

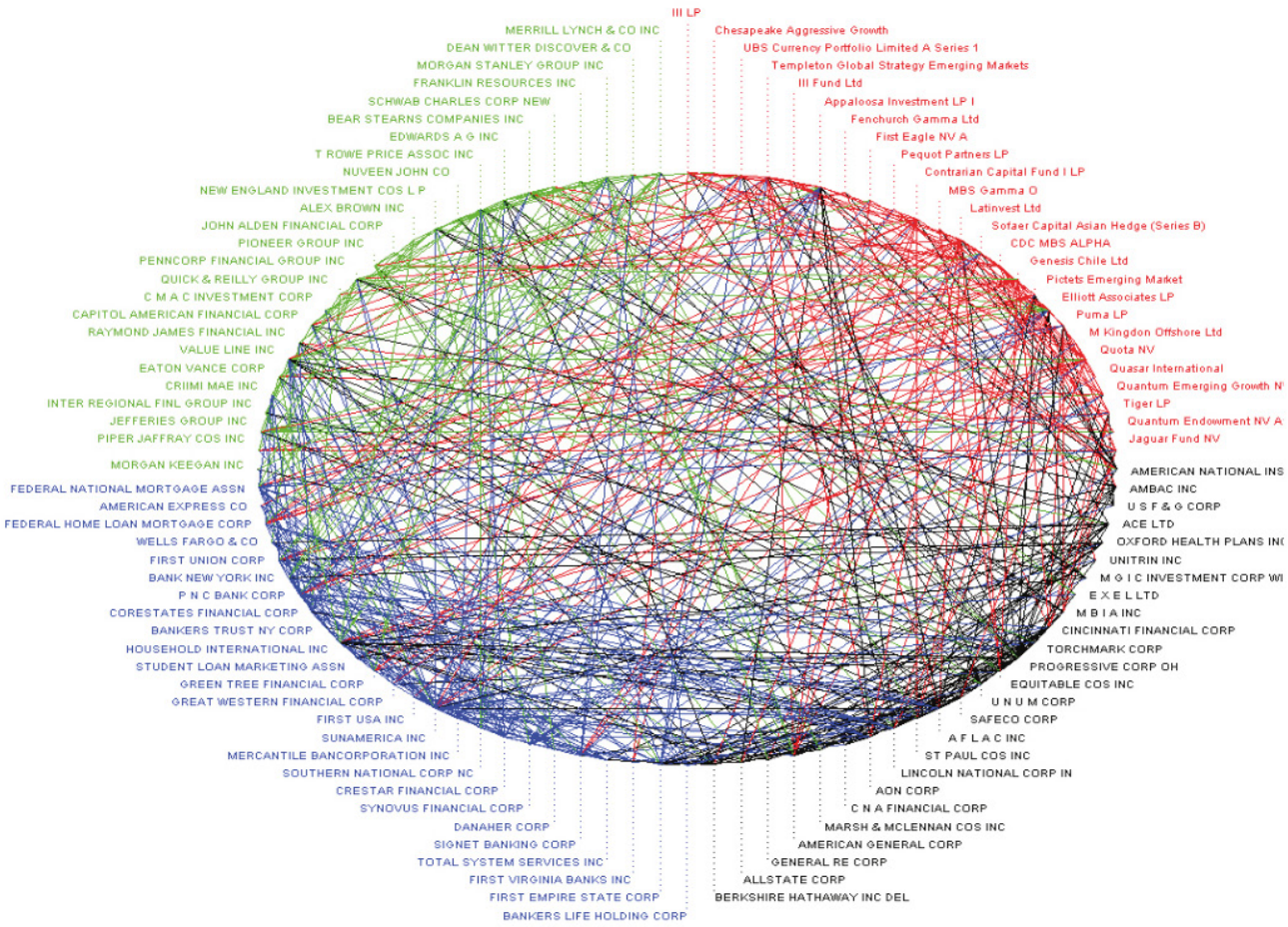


Figure 19: Network Diagram of connections between, banks, brokers/dealers, insurers and hedge funds. Jan 1994-Dec 1996
Source: https://app.box.com/shared/oesro8zzco0mtvuymh3f

17-Jul-13 IMF launches "Systemic Risk Monitoring ("SysMo") Toolkit—A User Guide" [333]

– Policy

In order to mitigate or prevent systemic risk, it needs to be monitored. In this paper, the authors set out to clarify the nature and use of the systemic risk monitoring tools that are currently available, providing guidance on how to select the best set of tools depending on the circumstances. The paper breaks down the tools into four categories, each with their strengths and weaknesses:

– Single risk/soundness indicators. [334] Indicators based on balance sheet data, such as financial soundness indicators (FSIs), are widely available and cover many risk dimensions. However, they tend to be backward-looking and do not account for probabilities of default or correlation structures. Moreover, only some of these indicators can be used as early-warning tools (e.g., indicators of funding structures). Market data can be used to construct complementary indicators for higher-frequency risk monitoring.

– Fundamentals-based models [335] rely on macroeconomic or balance sheet data to help assess macro-financial linkages (e.g., macro stress testing or network models). By providing vulnerability measures based on actual interconnectedness and exposures, these models may help build a realistic "story". However, they often require long-term data series, assume that parameters and relationships are stable under stressed conditions, and produce only low-frequency risk estimates.

– Market-based models. [336] These models uncover information about risks from high-frequency market data and are thus suitable for tracking rapidly-changing conditions of a firm or sector. These approaches are more dynamic, but their capacity to reliably predict financial stress has yet to be firmly established.

– Hybrid, structural models. [337] These models estimate the impact of shocks on key financial and real variables (e.g., default probabilities, or credit growth) by integrating balance sheet data and market prices. Examples include the CCA and distance-to-default measures, which compare the market value of an entity's assets to its debt obligations.

The paper concludes, however, that the systemic risk monitoring toolkit is incomplete and that "tools exist to assess most sectors and levels of aggregation, but they provide only partial coverage of potential risks and only tentative signals on the likelihood and impact of systemic risk events. As such, they may not provide sufficient comfort to policymakers."

23-Dec-13: Citigroup analysis reports reduced systemic political and financial risks in 2013 and 2014 [338]

– Initiative

Tracking the ebb and flow of the likelihood of various risks is important for estimating where best to direct energy and resources. Even approximate, order of magnitude estimates are sufficient if they establish that some risks are much more dangerous than others (order of magnitude estimates correspond to the "Class 5 cost estimate", [339] undertaken at the very beginning of the project, between 0% and 2% of its completion). In 2013, Citigroup analysts predicted that (with caveats) systemic risks would recede in Europe during the year, a prediction which seems to have been vindicated by events. As for the future, Tina Fordham, chief global political analyst at Citigroup Global Markets, predicted that "systemic political risks will decline in 2014, but country-level and geopolitical risks remain significant." It seems positive both that market analysts are tracking systemic risks and that they see them as decreasing (though their focus is mainly on political and financial systemic risks).

3.2 Exogenic risk

3.2.1 Major Asteroid Impact

When large objects strike terrestrial planets like the Earth, there can be significant physical and biospheric consequences, though atmospheres mitigate many surface impacts by slowing an object's entry.

Impact structures are dominant landforms on many of the solar system's solid objects and present the strongest empirical evidence for their frequency and scale. [340]

3.2.1.1 Expected impact

Asteroids have caused significant extinction events throughout the Earth's history. The most famous is the Chicxulub impactor, which probably helped cause the extinction of the non-avian dinosaurs and more than 75% of all species.[341] Large asteroid collisions – objects 5 km or more in size – happen approximately once every twenty million years and would have an energy a hundred thousand times greater[342] than the largest bomb ever detonated.[343] A land impact would destroy an area the size of a nation like Holland.[344] Larger asteroids could be extinction level events.

Asteroid impacts are probably one of the best understood of all risks in this report. Their mechanisms and frequencies are reasonably well estimated.[345] Recent ground- and space-based[346] tracking projects have been cataloguing and tracking the largest asteroids,[347] and have discovered that the risks were lower than was previously feared.[348] The projects are now cataloguing asteroids of smaller size and damage potential.

There has been some speculation about possible methods for deflecting asteroids[350], should they be found on a collision course with the planet. Such means remain speculative, currently, but may become more feasible given technological progress and potentially more affordable access to space.[351]

Should an impact occur, though, asteroid impact risks are similar to those of super-volcanoes, in that the main destruction will not be wrought by the initial impact, but by the clouds of dust projected into the upperatmosphere. The damage from such an "impact winter" could affect the climate, damage the biosphere, affect food supplies, and create political instability. Though humanity currently produces enough food to feed all humans,[352] this supply is distributed extremely unevenly, and starvation still exists. Therefore a disruption that is small in an absolute sense could still cause mass starvation in the future. Mass starvation, mass migration, political instability and wars could be triggered, possibly leading to a civilisation collapse. Unless the impact is at the extreme end of the damage scale and makes the planet unviable, human extinction is possible only as a consequence of civilisation collapse and subsequent shocks.[353]

3.2.1.2 Probability disaggregation

Five important factors in estimating the probabilities and impacts of the challenge:

1. Whether detection and tracking of asteroids and other dangerous space objects is sufficiently exhaustive.
2. How feasible it is to deflect an asteroid.
3. Whether measures such as evacuation could reduce the damage of an impact.
4. The short- and long-term climate consequences of a collision.
5. Whether our current civilisation could adapt to a post-impact world.

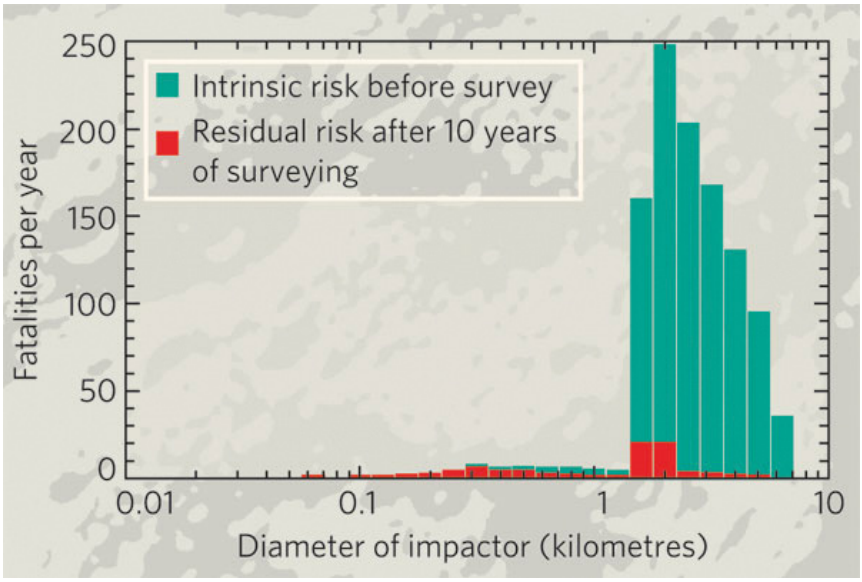
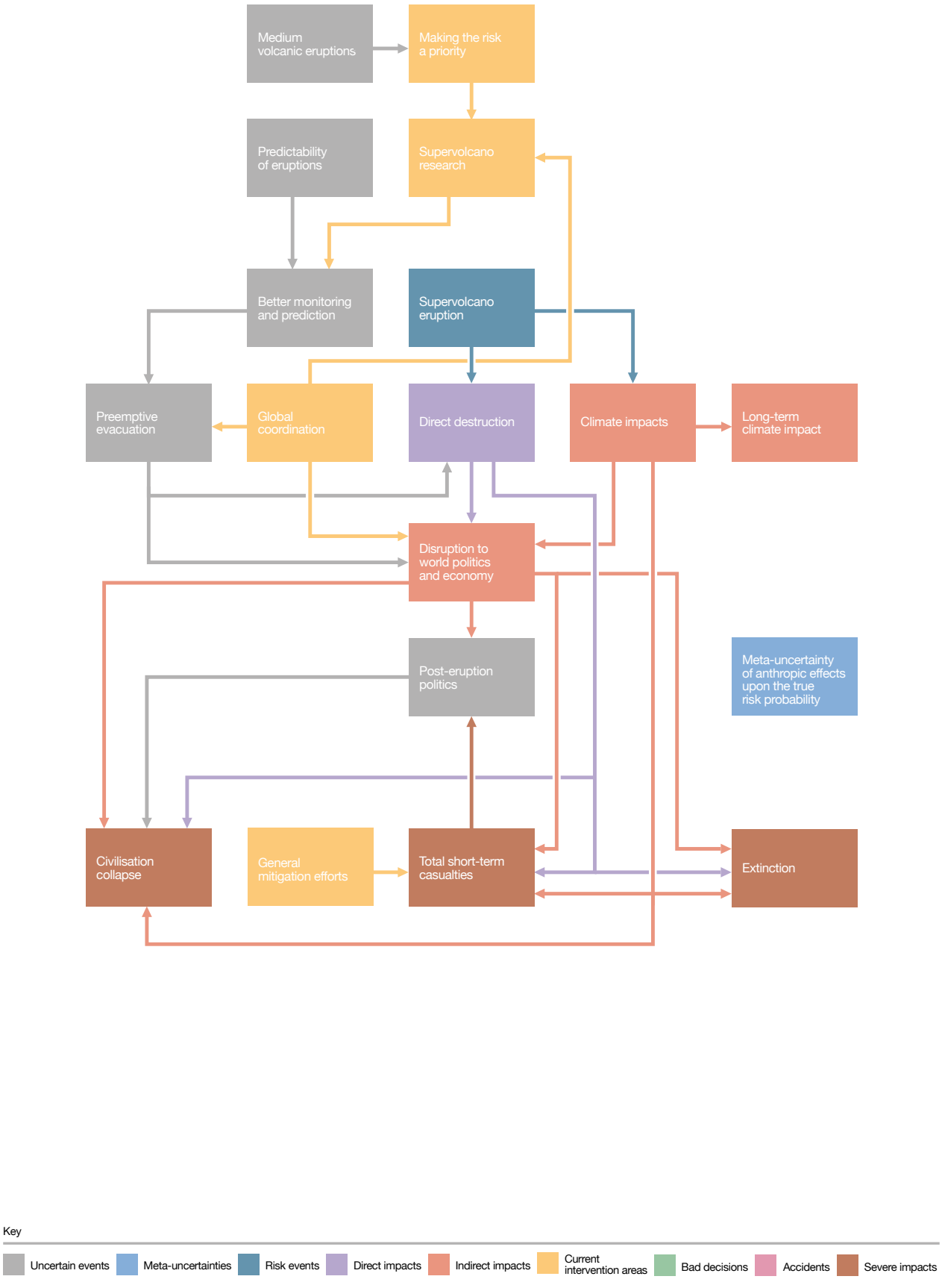


Figure 20: How the Spaceguard Survey has reduced the short-term risk of impacts from near-Earth objects[349]


Medium volcanic eruptions
Making the risk a priority
Predictability of eruptions
Supervolcano research
Better monitoring and prediction
Supervolcano eruption
Preemptive evacuation
Global coordination
Direct destruction
Climate impacts
Long-term climate impact
Disruption to world politics and economy
Post-eruption politics
Meta-uncertainty of anthropic effects upon the true risk probability
Civilisation collapse
General mitigation efforts
Total short-term casualties
Extinction
Key
Uncertain events
Meta-uncertainties
Risk events
Direct impacts
Indirect impacts
Current intervention areas
Bad decisions
Accidents
Severe impacts

1. Competition between private space programmes could be a determining factor in reducing the cost of space flight.

2. National space programmes have always provided the impetus for space flight projects, especially the more speculative and cutting-edge ones.

3. Protecting against asteroid impacts is already accepted as a project worth funding, but increased focus on the problem could increase the ability to predict and prevent such impacts.

4. Asteroid detection and tracking continues to progress well currently, and is key to preventing such collisions in future.

5. Better global coordination is not strongly needed to track or deflect asteroids, but would be important if a large-scale evacuation was needed.

6. General mitigation efforts may help reduce the direct and indirect negative impact of an impact, by, for instance, equipping people to deal with the changed climate.

7. Unlike many risks, there is no upper bound on how destructive an asteroid impact could be, though the largest impacts are the rarest.

8. The aftermath of an impact could greatly disrupt the world economic and political system.

9. Climate impacts would be the most destructive consequences of medium-scale meteor impacts, with the world plunged into an "impact winter".

10. The effects of an impact winter could last for a long time.

11. Easier access to space would be important for any plans to actually deflect an asteroid.

12. There are currently no asteroid deflection abilities, but there are many plans that could conceivably be implemented in due course.

13. Small asteroid impacts could motivate increased anti-asteroid precautions.

14. With enough warning, it could be possible to pre-emptively evacuate the impact area.

15. Post-impact politics will be important for reconstruction, adapting to the changed climate, and prevention of further harm.

16. Estimating the likelihood of asteroid impacts suffers from "anthropic shadow" effects: [355] we may be underestimating the danger because if there had been many more impacts in recent times, humans would not currently be around to observe their effects and take them into account.

Source: http://en.wikipedia.org/wiki/File:Chelyabinsk_meteor_trace_15-02-2013.jpg

3.2.1.3 Main events during 2013

15-Feb-13: Chelyabinsk meteor causes large fireball [356]
– Event

The Chelyabinsk meteor was a near-Earth asteroid that entered Earth's atmosphere over Russia, with an estimated speed of 18.6 km/s, almost 60 times the speed of sound. It exploded into a very visible air burst over Chelyabinsk Oblast, which was recorded by numerous video sources. The meteor was undetected before it entered the Earth's atmosphere, and caused numerous injuries, extensive damage, but no deaths. It was the largest to crash to Earth since 1908, [357] when an object hit Tunguska in Siberia.[358] The meteor seemed ideal from the risk reduction perspective: a large, visible impact that attracted great attention, and a renewed commitment to asteroid precautions, [359] but no actual fatalities.

19-Jun-13: Space Research Institute of Russian Academy of Science presents a strategy to use small asteroids to deflect hazardous objects from the trajectory of collision with Earth [360]
– Research

Though the analysis and tracking of asteroids has progressed rapidly, [361] methods for deflecting a dangerous asteroid, should it be detected, remain speculative.[362] The Space Research Institute of the Russian Academy of Science introduces another approach: selecting small (10-15m) near-Earth asteroids and causing them to strike a larger dangerous one, altering its trajectory. The more suggestions and ideas there are for such deflections, the more likely it is that one of them will yield an implementable approach.

17-Oct-13: The probability for "Asteroid 2013 TV135" to impact Earth in 2032 is one in 63,000 [363]
– Event

NASA reports that a 400-metre asteroid has one chance in 63,000 of impacting the Earth. An asteroid this size would produce ocean-wide tsunamis or destroy land areas the size of a small state (Delaware, Estonia).[364] For comparison, the odds of dying from lightning strike are 1 in 83,930, of a snake, bee or other venomous bite or sting is 1 in 100,000, of an earthquake 1 in 131,890, and of a dog attack 1 in 147,717.[365] So the risk of asteroid death, though low, is comparable to commoner risks

28-Oct-13: United Nations to Adopt Asteroid Defence Plan [366]
– Policy

The UN plans to set up an International Asteroid Warning Group for member nations to share information about potentially hazardous space rocks. If astronomers detect an asteroid that poses a threat to Earth, the UN's Committee on the Peaceful Uses of Outer Space will help coordinate a mission to launch a spacecraft to slam into the object and deflect it from its collision course.

This marks the first time an international body has assigned responsibility for tracking and intercepting dangerous asteroids.

14-Nov-13: Risk of medium asteroid strike may be ten times larger than previously thought [367]
– Research

This paper analyses in detail the Chelyabinsk impact, estimated to have had an energy of 500 kilotonnes of TNT. It demonstrates problems with the standard methods for estimating the energy of collisions – derived from nuclear weapons results [368] – and from that deduces that the number of impactors with diameters of tens of metres may be an order of magnitude higher than estimated. It argues that this demonstrates a deviation from a simple power law, and thus that there is a non-equilibrium in the near-Earth asteroid population for objects 10 to 50 metres in diameter. This shifts more of the impact risk to asteroids of these sizes.

3-Dec-13: SpaceX launches into geostationary orbit [369]
– Initiative

Easy access to space is important for all asteroid deflection proposals.[370] Since America retired the Space Shuttle, [371] it has been putting its hope in private space companies.[372] The success of SpaceX opens the possibility of eventual cheaper access to space.

NEO diameter	Yeld Megatonnes (MT*)	Crater diameter (km)	Average interval b/w impact (years)	Consequences
	<10			Upper atmosphere detonation of “stones” (stony asteroids) and comets; only “irons” (iron asteroids) <3% penetrate to surface.
75m	10 to 100	1.5	1,000	Irons make craters (Barringer Crater); Stones produce air-bursts (Tunguska). Land impacts could destroy area the size of a city (Washington, London, Moscow).
160m	100 to 1,000	3	4,000	Irons and stones produce ground-bursts; comets produce air-bursts. Ocean impacts produce signifi-cant tsunamis. Land impacts destroy area the size of a large urban area (New York, Tokyo).
350m	1,000 to 10,000	6	16,000	Impacts on land produce craters ocean-wide tsunamis are produced by ocean impacts. Land impacts destroy area the size of a small state (Delaware, Estonia).
700m	10,000 to 100,000	12	63,000	Tsunamis reach hemispheric scales, exceed damage from land impacts. Land impacts destroy area the size of a moderate state (Virginia, Taiwan).
1.7km	100,000 to 1 million	30	250,000	Both land and ocean impacts raise enough dust to affect climate, freeze crops. Ocean impacts generate global scale tsunamis. Global destruction of ozone. Land impacts destroy area the size of a large state (California, France, Japan). A 30 kilometre crater pen-etrates through all but the deepest ocean dephts.
3km	1 million to 10 million	60	1 million	Both land and ocean impacts raise dust, change climate. Impact ejecta are global, triggering wide-spread fires. Land impacts destroy area size of a large nation (Mexico, India).
7km	10 million to 100 million	125	10 million	Prolonged climate effects, global conflagration, probable mass extinction. Direct destruction ap-proaches continental scale (Australia, Europe, Usa).
16km	100 million to 1 billion	250	100 million	Large mass extinction (for example K/T or Creta-ceous-Tertiary geological boundary).
	>1 billion			Threatens survival of all advanced life forms.

Figure 15: Impact effects by size of Near Earth Object[354]

3.2 Current risk

3.2.2 Super-volcano

A super-volcano is any volcano capable of producing an eruption with an ejecta volume greater than 1,000 km3. This is thousands of times larger than normal eruptions.

Super-volcanoes can occur when magma in the mantle rises into the crust from a hotspot but is unable to break through it, so that pressure builds in a large and growing magma pool until the crust is unable to contain the pressure. [373]

3.2.2.1 Expected impact

The eruption which formed the Siberian Traps was one of the largest in history. It was immediately followed by the most severe wave of extinction in the planet's history, [374] the Permian–Triassic extinction event, [375] where 96% of all marine species and 70% of terrestrial vertebrate species died out. Recent research has provided evidence of a causal link: that the eruption caused the mass extinction.[376] There have been many other super-volcanic eruptions throughout history.[377] The return period for the largest super-volcanoes (those with a Volcanic Explosivity Index[378] of 8 or above) has been estimated from 30,000 years[379] at the low end, to 45,000 or even 700,000 years[380] at the high end.

Many aspects of super-volcanic activity are not well understood as there have been no historical precedents, and such eruptions must be reconstructed from their deposits.[381]

The danger from super-volcanoes is the amount of aerosols and dust projected into the upper atmosphere. This dust would absorb the Sun's rays and cause a global volcanic winter. The Mt Pinatubo eruption of 1991 caused an average global cooling of surface temperatures by 0.5°C over three years, while the Toba eruption around 70,000 years ago is thought by some to have cooled global temperatures for over two centuries.[382] The effect of these eruptions could be best compared with that of a nuclear war. The eruption would be more violent than the nuclear explosions,[383] but would be less likely to ignite firestorms and other secondary effects. Unlike nuclear weapons, a super-volcano would not be targeted, leaving most of the world's infrastructure intact.

The extent of the impact would thus depend on the severity of the eruption - which might or might not be foreseen, depending on improvements in volcanic predictions[384] - and the subsequent policy response. Another Siberian Trap-like eruption is extremely unlikely on human timescales, but the damage from even a smaller eruption could affect the climate, damage the biosphere, affect food supplies and create political instability.

A report by a Geological Society of London working group notes: "Although at present there is no technical fix for averting super-eruptions, improved monitoring, awareness-raising and research-based planning would reduce the suffering of many millions of people." [385]

Though humanity currently produces enough food to feed everyone,[386] this supply is distributed extremely unevenly, and starvation still exists. Therefore a disruption that is small in an absolute sense could still cause mass starvation. Mass starvation, mass migration, political instability and wars could be triggered, possibly leading to a civilisation collapse.

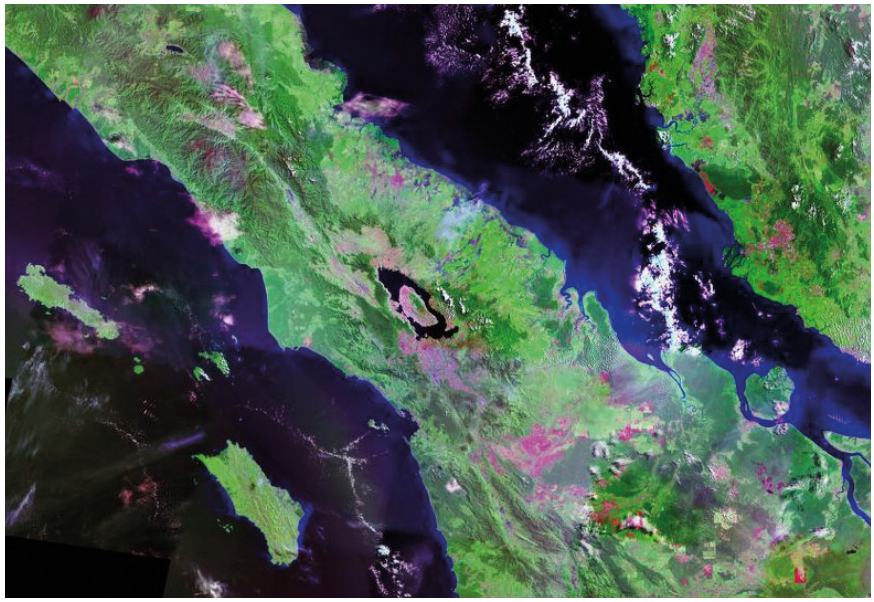
Unless the eruption is at the extreme end of the damage scale and makes the planet unviable, human extinction is possible only as a consequence of civilisation collapse and subsequent shocks.[387]

Prof. Michael Rampino, New York University, has estimated that a large (1,000 cubic kilometres of magma) super-eruption would have global effects comparable to an object 1.5km in diameter striking the Earth.[388]

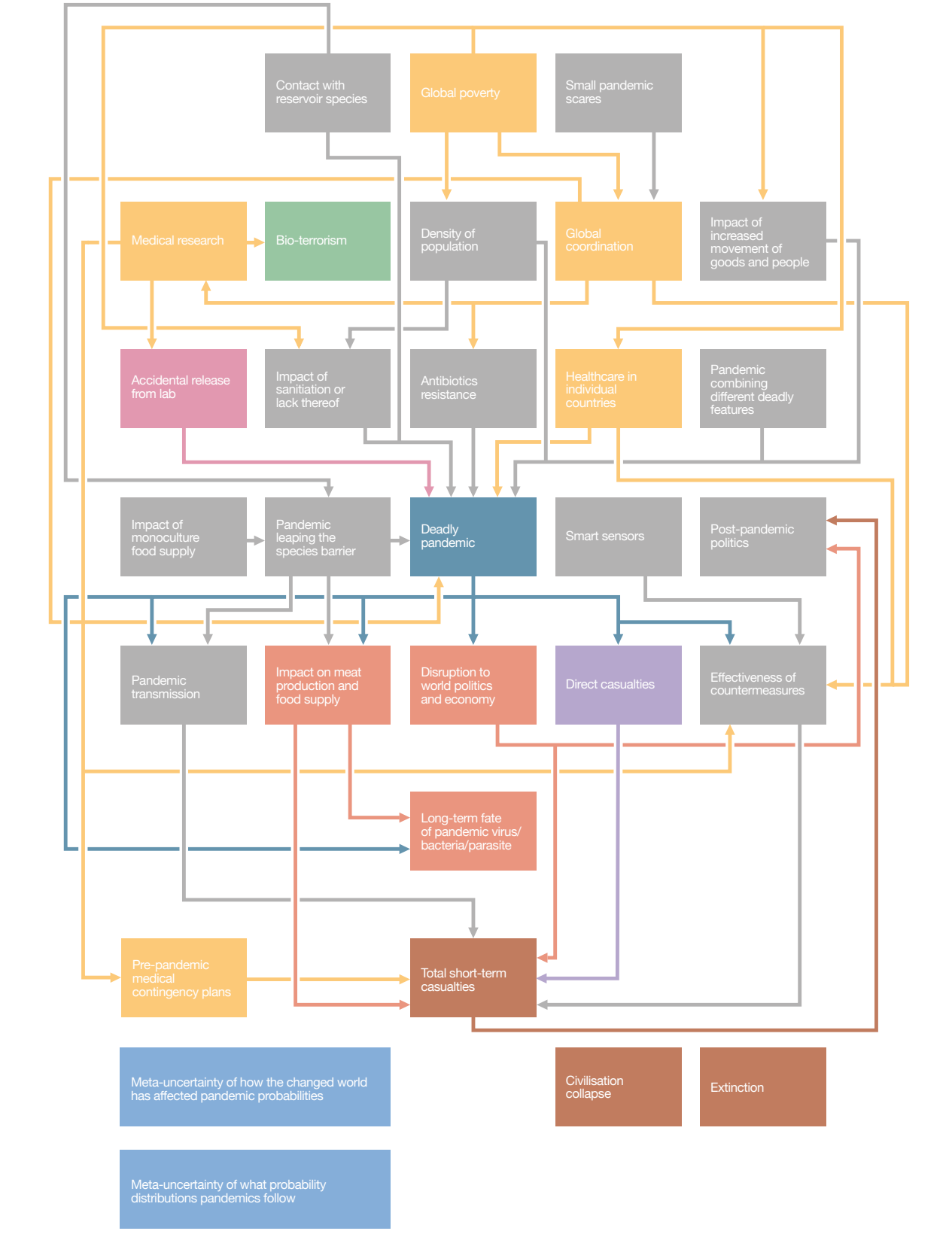
3.2.2.2 Probability disaggregation

Five important factors in estimating the probabilities and impacts of the challenge:

1. Whether countries will coordinate globally against super-volcano risk and damage.
2. The predictability of super-volcanic eruptions.
3. How directly destructive an eruption would be.
4. The effectiveness of general mitigation efforts.
5. How severe the long-term climate effects would be.



Satellite image of Lake Toba
Source: NASA, http://en.wikipedia.org/wiki/File:Toba_overview.jpg


Contact with reservoir species
Global poverty
Small pandemic scares
Medical research
Bio-terrorism
Density of population
Global coordination
Impact of increased movement of goods and people
Accidental release from lab
Impact of sanitiation or lack thereof
Antibiotics resistance
Healthcare in individual countries
Pandemic combining different deadly features
Impact of monoculture food supply
Pandemic leaping the species barrier
Deadly pandemic
Smart sensors
Post-pandemic politics
Pandemic transmission
Impact on meat production and food supply
Disruption to world politics and economy
Direct casualties
Effectiveness of countermeasures
Long-term fate of pandemic virus/ bacteria/parasite
Pre-pandemic medical contingency plans
Total short-term casualties
Meta-uncertainty of how the changed world has affected pandemic probabilities
Civilisation collapse
Extinction
Meta-uncertainty of what probability distributions pandemics follow
Key
Uncertain events
Meta-uncertainties
Risk events
Direct impacts
Indirect impacts
Current intervention areas
Bad decisions
Accidents
Severe impacts

1. Whether super-volcano risk is made a priority will have a large impact on research and volcano monitoring.

2. Further super-volcano research will be important in any mitigation and monitoring efforts.

3. Global coordination and cooperation between nations will determine research levels, the chances of evacuations, and post-eruption disruption to the world political and economic system.

4. General mitigation efforts may help reduce the direct and indirect negative impact of an eruption, by, for instance, equipping people to deal with the changed climate.

5. The direct destructive effect of a super-volcano can be extensive, especially in the area around the eruption.

6. A super-volcano's main destructive impact is through its effect on the climate, akin to a nuclear winter cooling effect. This will strongly affect all impact levels, and the disruption to the world's political and economic system.

7. The level of this disruption will determine how well countries cope with the aftermath of the eruption and subsequent climate changes, and whether subsequent conflicts or trade wars will occur, adding to the damage.

8. The long-term climate impact will determine in what state the post-eruption world will find itself, relevant both for reconstruction after a collapse and for preventing such a collapse.

9. Whether eruptions are fundamentally predictable or not, and how far in advance, will be very important for many mitigation strategies.

10. Better volcano monitoring and prediction (if possible) will allow such interventions as pre-emptive evacuations.

11. Evacuations are likely to be the only effective response to an imminent eruption, as super-volcanoes are unlikely to be controllable or divertible.

12. Post-eruption politics will be a consequence of the number of short-term casualties, and the disruption to the world system.

13. Medium scale volcanic eruptions may persuade leaders to make the risk more of a priority.

14. Estimating the likelihood of super-volcanic eruptions suffers from "anthropic shadow" effects: [390] we may be underestimating the danger because if there had been many more eruptions in recent times, humans would not currently be around to observe their effects and take them into account.

VEI	Ejecta volume	Classification	Description	Plume	Frequency
0	< 10,000 m^3	Hawaiian	Effusive	< 100 m	constant
1	> 10,000 m^3	Hawaiian / Strombolian	Gentle	100-1000 m	daily
2	> 1,000,000 m^3	Strombolian / Vulcanian	Explosive	1-5 km	weekly
3	> 10,000,000 m^3	Vulcanian / Peléan	Catastrophic	3-15 km	few months
4	> 0.1 km^3	Peléan / Plinian	Cataclysmic	10-25 km	≥ 1 yr
5	> 1 km^3	Plinian	Paroxysmic	20-35 km	≥ 10 yrs
6	> 10 km^3	Plinian / Ultra-Plinian	Colossal	> 30 km	≥ 100 yrs
7	> 100 km^3	Ultra-Plinian	Mega-colossal	> 40 km	≥ 1,000 yrs
8	> 1,000 km^3	Supervolcanic	Apocalyptic	> 50 km	≥ 10,00 yrs

Figure 21: Volcanic Explosivity Index [389]

3.2.2.3 Main events during 2013

15-Mar-13: Climate impact of super-volcanoes may be less than previously thought [391]

– Research

The Toba eruption around 70,000 years ago was one of the world's largest super-volcanic eruptions. In contrast with some theories that claim it caused a volcanic winter that may have lasted over two centuries, [392] this paper claims that analysis of ash from the Toba super-eruption in Lake Malawi shows no evidence of volcanic winter in East Africa. This further illustrates the difficulty of establishing the exact impact of large-scale disasters, when the evidence record is poor.

17-Jul-13: The Volcanological Society of Japan looks at volcano and super-volcano mitigation [393]

– Policy

Prevention of super-volcano eruptions is impossible with current technology, but there may be some possibility of mitigating their effects. The Volcanological Society of Japan is one of the few organisations that have looked at such potential mitigation.

They put the risk of super-volcanic eruptions in the context of standard volcanic eruptions, just on a larger scale (noting that super-volcanic eruptions have affected Japan in the past). Japan has been a very seismically active country for its entire history,[394] so it might be hoped that adequate volcanic mitigation measures would have been implemented.

But the report notes that "remarkably few [of Japan's local governments] have drafted volcanic disaster countermeasure[s]", [395] adding that "Local governments that have actually experienced a volcanic disaster focus attention on volcanic disaster-related discussion, but most have not drafted specific procedures for volcanic disasters and seem to think that the general disaster countermeasure volume is adequate." This provokes some pessimism about the likelihood of effective planetary super-volcano mitigation measures being implemented, especially in those areas with no direct experience of volcanic risk.

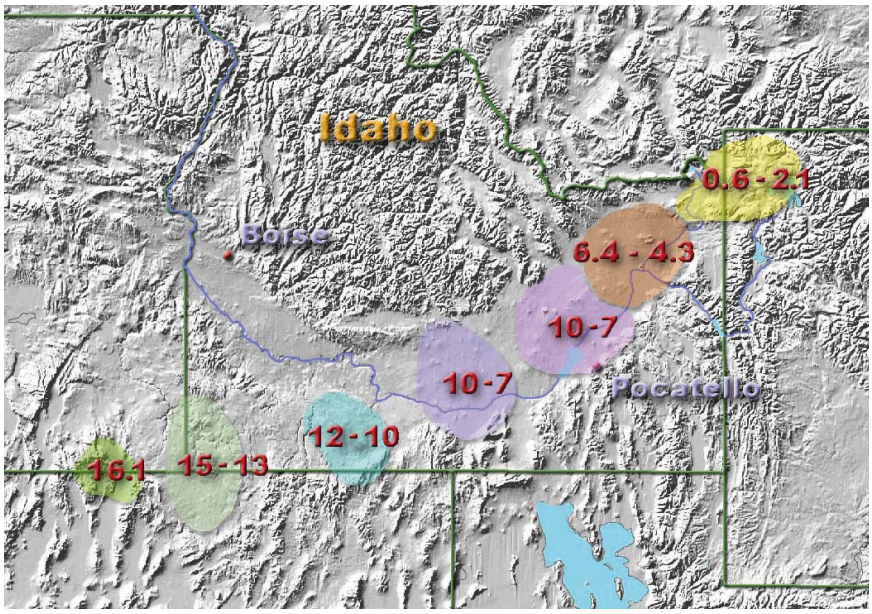
This is due to the normalcy bias, "the tendency to minimise the probability of potential threats or their dangerous implications,". [396]

27-Oct-13: Yellowstone super-volcano larger than previously thought [397]

– Research

Another continuing development in the science of super-volcanoes, this paper demonstrates that the crustal magma reservoir under Yellowstone was 50% larger than was previously thought. However, despite this increase, integrated probabilistic hazard assessment shows that the biggest Yellowstone Plateau threat is from large M7+ earthquakes - significantly damaging[398], but very unlikely to threaten billions - not from volcanic or super-volcano eruptions.

Figure 22: Location of Yellowstone hotspot over time (numbers indicate millions of years before the present). Source: http://en.wikipedia.org/wiki/File:HotspotsSRP.jpg



15-Nov-13: Insurance executives rank super-volcanoes low on the list of extreme risks [399]

– Initiative

Academics have long worried about the probability of super-volcanic eruptions. But academia attracts certain types of people with specific outlooks, who can be subject to further biases because of their profession and the social milieu surrounding it.[400] Insurers come from a different background, focusing on practical profitability in the business world and using a relatively short time horizon. So it is instructive that they do not see super-volcanoes as a major threat in the world today: "Of interest to us is the very low ranking of the user-submitted idea of super-volcanoes in the US".

20-Dec-13: Super-volcano confirmed as responsible for one of the largest extinctions in history [401]

– Research

The maximal destructive potential of super-volcanoes is uncertain. There have been large super-volcanic eruptions throughout history, [402] and many extinction events, but uncertainties in the geological record mean that it was hard to establish whether they were causally linked. One eloquent example was the eruption which formed the Siberian Traps[403] (one of the largest in history), and the Permian–Triassic extinction, [404] where 96% of all marine species and 70% of terrestrial vertebrates died out. The two events were close on the geological timeline, and this paper, using recent dating techniques, confirmed that the super-volcano erupted shortly before the extinction, making it the likely culprit. The risk of large impacts from super-volcanoes has thus gained in plausibility.

3.3 Emerging risk

3.3.1 Synthetic Biology

Synthetic biology is the design and construction of biological devices and systems for useful purposes. It is an area of biological research and technology that combines biology and engineering, and so often overlaps with bioengineering and biomedical engineering.

It encompasses a variety of different approaches, methodologies, and disciplines with a focus on engineering biology and biotechnology. [405]

3.3.1.1 Expected impact

Pandemics are one of the worst killers in human history. Synthetic biology is the design and construction of biological devices and systems to accomplish the specific goal of the synthetic biologist,[406] adding human intentionality to traditional pandemic risks.

The positive and negative potentials of synthetic biology are unclear[407] – much of the information currently comes from synthetic biologists, [408] who may not be able to provide an impartial overview (the problem is exacerbated by the decentralised nature of the field[409]). Attempts at regulation[410] or self-regulation[411] are currently in their infancy, and may not develop as fast as research does.[412]

One of the most damaging impacts from synthetic biology would come from an engineered pathogen,[413] targeting humans or a crucial component of the ecosystem (such as rice, which accounts for 20% of all calories consumed by humans).[414]

This could emerge through military bio-warfare, [415] commercial bio-warfare, [416] bio-terrorism[417] (possibly using dual-use products[418] developed by legitimate researchers, and currently unprotected by international legal regimes[419]), or dangerous pathogens leaked from a lab[420]. Of relevance is whether synthetic biology products become integrated into the global economy or biosphere. This could lead to additional vulnerabilities (a benign but widespread synthetic biology product could be specifically targeted as an entry point through which to cause damage). But such a development would lead to greater industry and academic research, which could allow the creation of reactive or pre-emptive cures.[421]

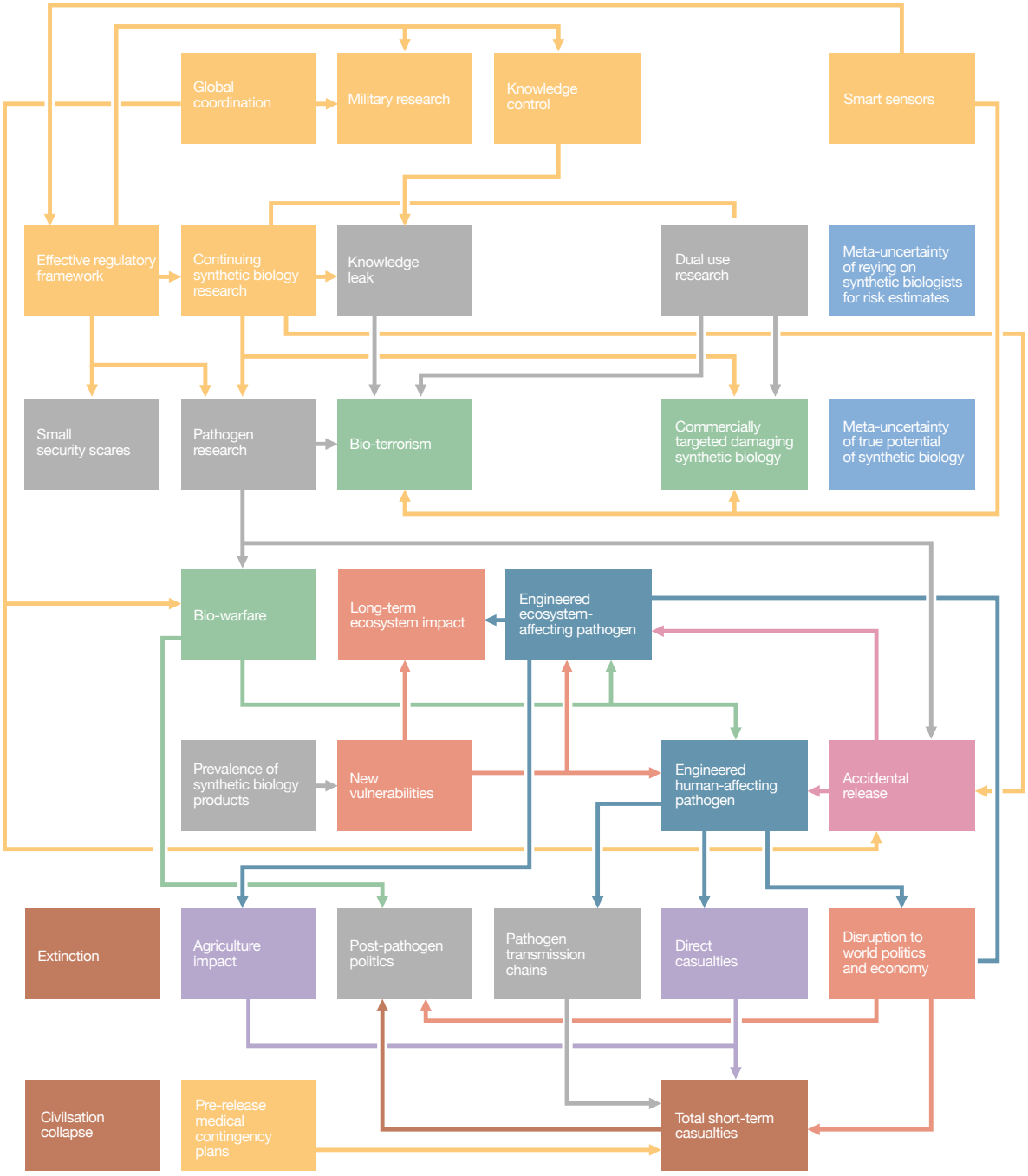
The impact is very similar to that of pandemics: mass casualties and subsequent economic and political instabilities leading to possible civilisation collapse. A bio-war would contribute greatly to the resulting instability. Even for the most perfectly engineered pathogen, survivors are likely, if only in isolated or mainly isolated locations.[422]

Extinction risk is unlikely, [423] but possible if the aftermath of the epidemic fragments and diminishes human society to the extent that recovery becomes impossible[424] before humanity succumbs to other risks.[425]

3.3.1.2 Probability disaggregation

Five important factors in estimating the probabilities and impacts of the challenge:

1. The true destructive potential of synthetic biology, especially the tail risk.
2. Whether the field will be successfully regulated, or successfully manage to regulate itself.
3. Whether the field will usher in a new era of bio-warfare.
4. Whether the tools of synthetic biology can be used defensively to create effective counter measures.
5. The dangers of relying on synthetic biologists to estimate the danger of synthetic biology.



Key

Uncertain events | Meta-uncertainties | Risk events | Direct impacts | Indirect impacts | Current intervention areas | Bad decisions | Accidents | Severe impacts

1. Global coordination and cooperation will be important to preventing biowarfare and creating an effective regulatory framework.

2. Military research in synthetic biology would be a direct risk for creating dangerous bio-weapons.

3. Effective and intelligent regulatory frameworks are the great challenge for controlling synthetic biology risks. The field is currently self-regulated, and it isn't clear whether this is sufficient.

4. Synthetic biology is novel enough for some parts of the field potentially to be shut down if they are seen to be too dangerous: continuing synthetic biology research is not a given.

5. Of all technological fields, synthetic biology could be one requiring knowledge control: where dangerous knowledge (such as how to synthesise certain pathogens) is kept out of the public domain. Other dangerous technologies (e.g. nuclear weapons) require a large project or rare materials, and could be regulated at that level instead.

6. Mass surveillance and smart sensors may be needed to ensure dangerous synthetic biology projects are not carried out.

7. Most of the pre-release mitigation efforts are similar to those for fighting a conventional pandemic.

8. Biowarfare is one major scenario in which synthesised biological agents are targeted at humans or at the ecosystem.

9. Commercial enterprises, especially those exploiting natural resources, may be tempted to target their rival's products with pathogens that may get out of control.

10. Bio-terrorism has the potential to be the most destructive form of terrorism of all, with a small group causing billions of casualties.

11. The various products produced by synthetic biology research could be deadly if accidentally released.

12. It is hard to estimate ahead of time, but the direct casualties of an engineered pathogen could potentially include everyone infected, which could include almost everyone alive.

13. The most devastating pathogen affecting the ecosystem would be one targeting food production in one form or another.

14. The widespread use of synthetic biology products could introduce new vulnerabilities, if these products are specifically targeted.

15. Human- or ecosystem-targeting pathogens on a large scale could disrupt the world's political and economic system, especially if one party is blamed for their release.

16. Natural pathogens are unlikely to have a long-term devastating effect, but human-designed ones could – or they could be upgraded and changed regularly.

17. Small security scares could provide impetus to the development of effective regulations.

18. Knowledge leaks (such as genomes published online) could enable bioterrorism if the cost of producing pathogens is low.

19. Much legitimate synthetic biology research could have dual use for terrorists or as weapons.

20. It may be possible to control direct pathogen research through regulations – certainly more so than dual use products. This kind of research is the most likely to lead to bio-weapons, or to accidental release.

21. If synthetic biology products are prevalent, this may introduce new vulnerabilities.

22. Post-pathogen politics will be important for preventing civilisation collapses, and regulating further synthetic biology experiments and developments.

23. The pathogen transmission chains are important in determining the transmissibility of the pathogens in the human population, and whether quarantine or similar methods will be effective.

24. Synthetic biology research may enable the construction of effective preventative measures or countermeasures to an outbreak (both for a designed pathogen and a natural one).

25. The pathogen transmission chains are important in determining the transmissibility of the pathogens in the ecosystem, and the effectiveness of various countermeasures.

26. Of all risks, those of synthetic biology are the most uncertain: they could turn out to be very high, or very low; it is currently not known.

27. Active synthetic biologists are the major source of information on synthetic biology risks, which calls the impartiality of their estimates into question.

3.3.1.3 Main events during 2013

15-Jan-13: Improved bio-safety in iGEM synthetic biology competition [426]

– Initiative

A significant part of synthetic biology is developed by "bio-hackers", [427] small-scale operations with a hobbyist or competitive hacker ethos. This ethos would be more attracted to self-regulation[428] rather than outside governmental regulation. But industry self-regulations often fail in their goals (especially without explicit sanctions for malfeasance),[429] so it is currently unclear whether it can be relied upon to reduce risk. The International Genetically Engineered Machines (iGEM) competition is one of the largest in synthetic biology, and has attempted to promote bio-safety in its participants. It is significant for the potential of self-regulation that such attempts have been partially successful.

23-Jan-13: Work resumes on lethal 'flu strains [430]

– Event

In 2011, scientists working in avian 'flu research performed two experiments[431] showing how the 'flu virus could be made transmissible to ferrets (and, by extension, humans). This generated protests and calls for the papers to remain fully or partially unpublished, [432] because of the potential for misuse by bio-terrorists or bio-weapons programmes. In response, researchers in the field declared a voluntary moratorium in January 2012.[433] A year later, they decided to lift the moratorium.

One cannot expect workers in a field to be unbiased about their own research, [434] so it is significant that this decision was condemned by many scientists, including other virologists.[435] This provides strong evidence that ending the moratorium was a dangerous decision.

28-Feb-13: WHO report: Many countries and institutions lack oversight of "dual use" biological research, and there is a lack of global frameworks on the issue [436]

– Policy

Dual use biological research concerns life sciences research intended for benefit, but with results which might easily be misapplied to produce harm when used by bio-terrorists or in bio-weapon research. Examples of these included the experiments making avian 'flu transmissible to humans.[437] But there were other examples too, including: [438]

– Accidentally increasing the virulence of mousepox as part of an experiment to control mice as pests in Australia.[439]
– Variola virus immune evasion design.[440]
– Chemical synthesis of poliovirus cDNA.[441]
– Reconstruction of the 1918 'flu virus.[442]
– Creating and synthesising aminimal organism.[443]

As life science techniques develop, there is the potential for more such potentially dual use research in future. Yet, despite these dangers, the WHO reports that many countries and institutions lack oversight of such research, and that there is a lack of global frameworks on the issue.

01-Jun-13: Scientists create hybrid airborne H5N1 flu [444]

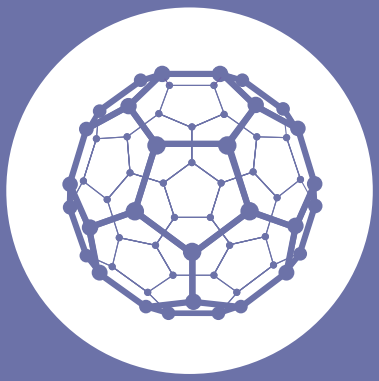
– Research

The H in H5N1 stands for "hemagglutinin", as depicted in this molecular model. Permission is granted to copy, distribute and/or modify this document under the terms of the GNU Free Documentation License, Version 1.2 or any later version published by the Free Software Foundation; with no Invariant Sections, no Front-Cover Texts, and no Back-Cover Texts. A copy of the license is included in the section entitled GNU Free Documentation

Hemagglutinin molecule
Source: http://en.wikipedia.org/wiki/File:Hemagglutinin_molecule.png

Research continues into gain of function (GOF) for different influenza viruses. This report detailed methods for airborne mammal-to-mammal transmission of the H5N1 'flu virus, when hybridised with a highly transmissible (and human-infective) H1N1 virus. There is a possibility that such viruses (or those created in similar GOF experiments) could become transmissible to humans, and potentially cause a pandemic if they escaped from the lab.

A report from the Center for Arms Control and Non-Proliferation[445] applied likelihood-weighted-consequence analysis to estimate the probability and impact of such escapes. It estimated that the risk was considerable: even if a rapid quarantine was instituted, each lab-year of such research carried an expected casualty rate of 180 to 1,100 fatalities, and $2.3 million to $390 million in economic damage.



3.3 Emerging risk

3.3.2 Nanotechnology

Nanotechnology, [446] *here defined as atomically precise manufacturing,* [447] *is the creation of effective, high-throughput manufacturing processes that operate at the atomic or molecular level.*

There are many suggested designs, [448] *but there are no immediately available methods to construct them.* [449]

3.3.2.1 Expected impact

It is currently unclear whether nanotechnology would be a revolution in manufacturing, or merely a continuation of current trends. Industry represents 30% of world GDP, [450] a declining fraction, so from a narrow economic perspective it could be argued that the impact of nanotechnology would be relatively small. However, nanotechnology could create new products – such as smart or extremely resilient materials[451] – and would allow many different groups or even individuals to manufacture a wide range of things.

This could lead to the easy construction of large arsenals of weapons by small groups.[452] These might be masses of conventional weapons (such as drones or cruise missiles), or more novel weapons made possible by atomically precise manufacturing. If this is combined with a possible collapse in world trade networks[453] – since manufacturing could now be entirely local – there would be a likely increase in the number of conflicts throughout the world. Of particular relevance is whether nanotechnology allows rapid uranium extraction and isotope separation[454] and the construction of nuclear bombs, which would increase the severity of the consequent conflicts. Unlike the strategic stalemate of nuclear weapons, nanotechnology arms races could involve constantly evolving arsenals and become very unstable.[455] These conflicts could lead to mass casualties and potentially to civilisation collapse if the world political and social system were too damaged.

Some nanotechnology pathways could mitigate these developments, however. Cheap mass surveillance, [456] for instance, could catch such re-armament efforts (though surveillance could have its own detrimental effects). Many of the world's current problems may be solvable with the manufacturing possibilities that nanotechnology would make possible, such as depletion of natural resources, pollution, climate change, clean water, and even poverty.[457] There are currently few applicable international legal regimes governing nanotechnology.[458]

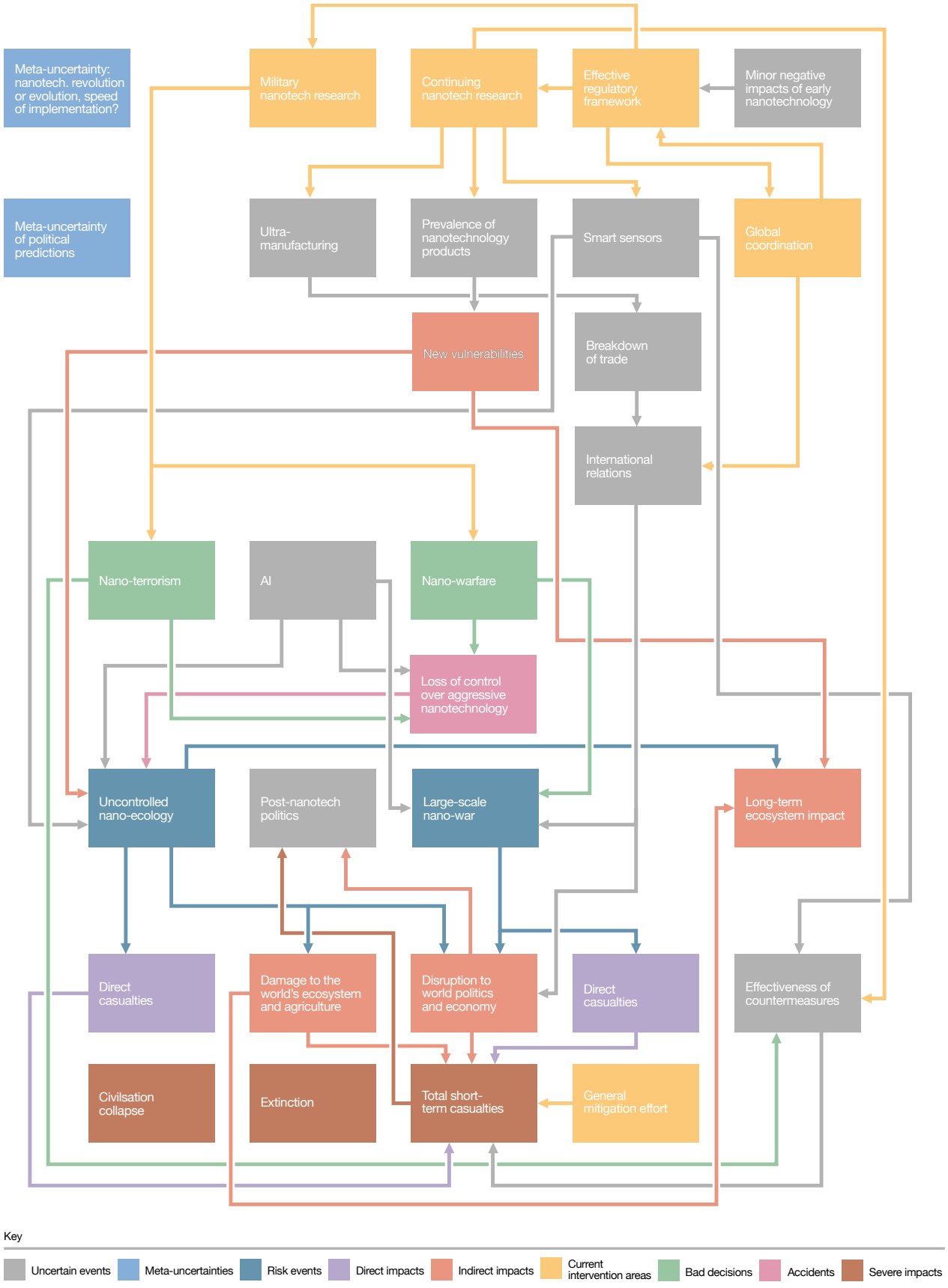
In the media the label "grey goo" [459] is sometimes applied to nanotechnology.. This is meant to describe a hypothetical situation where special self-replicating nanomachines would be engineered to consume the entire environment. It is unclear how effective they could be, and they play no role in atomically precise manufacturing.[460] Mass self-replication would be detectable, and vulnerable to human-directed counter-measures.[461] However, it is possible that such replicating machines could endure and thrive in particular ecological niches, where the cost of removing them is too high.[462] The misuse of medical nanotechnology[463] is another risk scenario.

Extinction risk is only likely as a long-term consequence of civilisation collapse, if the survivors are unable to rebuild and succumb to other threats.[464] The possibility of nanomachines or nanoweapons remaining active after a civilisation collapse may make the rebuilding more difficult, however, while the availability of atomically precise manufacturing systems, by contrast, could aid rebuilding.

3.3.2.2 Probability disaggregation

Five important factors in estimating the probabilities and impacts of the challenge:

1. The timeline for nanotech development.
2. Which aspects of nanotech research will progress in what order.
3. Whether it will be possible for small groups to assemble a weapons arsenal in a short period of time.
4. Whether nanotech tools can be effectively used defensively or for surveillance.
5. Whether nanotech tools or weaponry are made to be independent of human control.


Meta-uncertainty: nanotech. revolution or evolution, speed of implementation?
Military nanotech research
Continuing nanotech research
Effective regulatory framework
Minor negative impacts of early nanotechnology
Meta-uncertainty of political predictions
Ultra-manufacturing
Prevalence of nanotechnology products
Smart sensors
Global coordination
New vulnerabilities
Breakdown of trade
International relations
Nano-terrorism
AI
Nano-warfare
Loss of control over aggressive nanotechnology
Uncontrolled nano-ecology
Post-nanotech politics
Large-scale nano-war
Long-term ecosystem impact
Direct casualties
Damage to the world's ecosystem and agriculture
Disruption to world politics and economy
Direct casualties
Effectiveness of countermeasures
Civilsation collapse
Extinction
Total short-term casualties
General mitigation effort
Key
Uncertain events
Meta-uncertainties
Risk events
Direct impacts
Indirect impacts
Current intervention areas
Bad decisions
Accidents
Severe impacts

1. An effective regulatory framework could control the potential dangers of nanotechnology, though this depends very much on the nature of the problems and the design of the regulations. Regulating the potentially pollutant aspects of nanotechnology – such as micro-particles – would be more feasible under traditional frameworks, but somewhat tangential to the main issues.

2. Continuing research – into the transformative aspects, not just standard materials science – is required for nanotechnology to become a viable option for manufacturing.

3. Military nanotechnology research increases the chance that nanotechnology will be used for effective weapons production, and may lead to an arms race.

4. Global coordination allows for regulatory responses, and may mitigate the effect of possible collapse of trade routes.

5. The general mitigation efforts of most relevance to nanotechnology are probably in surveillance and improved international relations.

6. Nanoterrorism is one way in which humanity could lose control of aggressive nanotechnology.

7. Nanotechnology-empowered warfare could spiral out of control, or could lead to the deployment of uncontrolled aggressive nanotechnology. The risk would be acute if small groups were capable of effective nanowarfare on their own.

8. Uncontrolled aggressive nanotechnology is a scenario in which humanity unleashes weapons that it cannot subsequently bring under control, which go on to have independent negative impacts on the world.

9. The direct casualties of an uncontrolled nanotechnology are hard to estimate, as they depend critically on the nature of the nanotechnology, the countermeasures used, and the general technological abilities of the human race after nanotechnology development. The casualties from nanowarfare are similarly hard to determine, as it is unclear what would be the most effective military use of nanoweapons, and whether this would involve high or low casualties (contrast mass nuclear weapons with targeted shutdown of information networks).

10. Disruption of the world political and economic system (exacerbated by the collapse of trade routes or nanowarfare) could lead to further casualties.

11. A nano-ecology could disrupt and undermine the standard biological ecology, including food production.

12. The widespread use of nanotechnology could generate new vulnerabilities (just as modern cities are vulnerable to EMP (electro-magnetic pulse) weapons that would have had no effects in previous eras).

13. Over the long term, a nano-ecology could spread and develop in ways that are hard to predict or control (especially if there are new vulnerabilities to it).

14. Any problems with early nanotechnology could provide impetus for a regulatory or political response.

15. The prevalence of nanotechnology products could introduce new vulnerabilities.

16. Smart sensors of all kinds would be very important to either controlling a nano-ecology or preventing small groups from rapidly constructing arsenals of weapons.

17. A nano-ecology becomes considerably more dangerous if there is an intelligence controlling it (or pieces of it). Successful artificial intelligence could allow this to happen.

18. It is in its potential for extreme manufacturing that the promise and perils of nanotechnology lie.

19. Nanoweapon proliferation could completely destabilise international relations and arms control treaties, by allowing small groups to rapidly construct large arsenals.

20. One of the greatest threats of nanotechnology is the possibility that it could result in a breakdown of trade between currently interdependent nations.

21. International relations could break down if trade does, leading to much potential for conflict.

22. The effectiveness of countermeasures is extremely hard to judge, as is the balance between “defensive” and “offensive” nanoweaponry. Nanotechnology could allow novel approaches to controlling the problem, such as extremely effective sensors.
23. Post-nanotech politics will determine the risk of collapse and the potential for reconstruction.

24. Much of the analysis of the impact of nanotechnology proceeds by analogy with previous discoveries or economic changes. It is unclear whether evolution or revolution is the better analogy, and what the speed of implementation of nanotechnological discoveries will be.

25. The course of international politics is extremely hard to predict, even for political scientists.[465]

3.3.2.3 Main events during 2013

11-Jan-13: Artificial molecular assembly device created [466]

– Research

A functional and practical design for assembling molecules is an essential feature for successful nanotechnology. There have been many designs proposed, [467] and some constructed, but not yet a fully functional molecular assembly device.[468] This design, based on principles from biology (it uses messenger RNA as its input code, and synthesises peptides) represents another step towards that important goal.

06-May-13: First weapon made with 3D printer [469]

– Event

It is the ability to make weapons en masse that represents one of the dangers of nanotechnology.[470] 3D printing (or additive manufacturing)[471] is not nanotechnology, but can be considered a precursor, as it similarly allows small groups to design and manufacture their desired products themselves. That one of the early designs has been a functioning weapon, and that such weapon design was justified on moral grounds,[472] indicates a very high probability that nanotechnology will be used for weapon production.

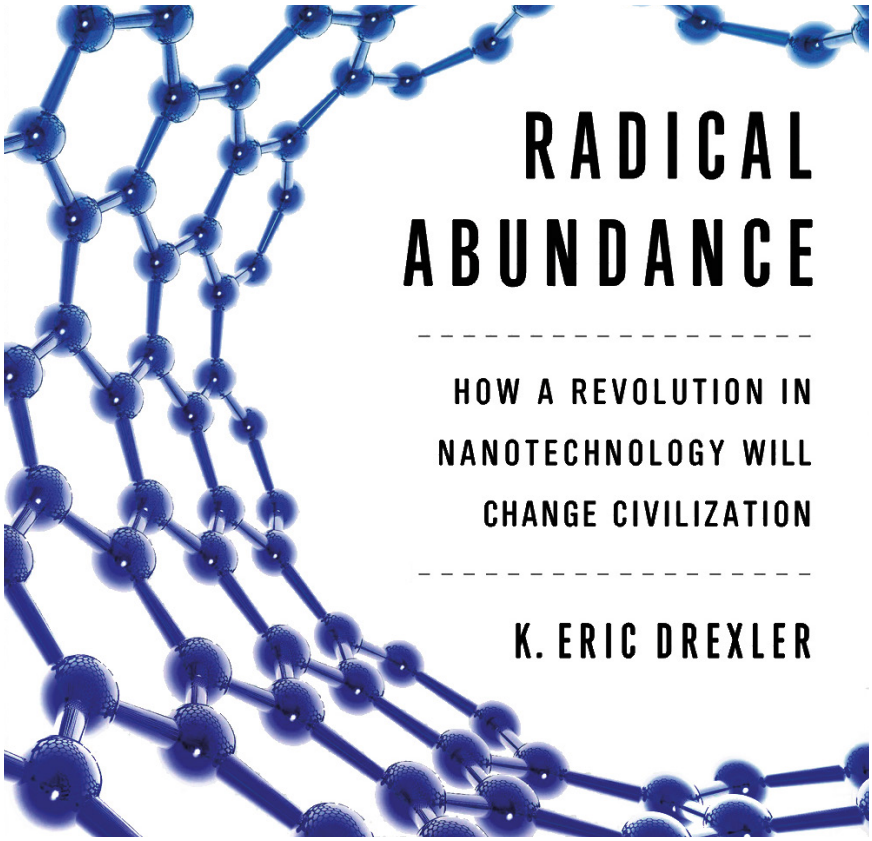
07-May-13: Publication of Eric Drexler's book "Radical Abundance: How a Revolution in Nanotechnology Will Change Civilization" [473]

– Research

Eric Drexler is one of the pioneers of nanotechnology, and introduced the concepts to the general public with his book "Engines of Creation".[474] Twenty seven years later, he presents a history, progress report, and updated version of his vision, the central theme of which is to "imagine a world where the gadgets and goods that run our society are produced not in far-flung supply chains of industrial facilities, but in compact, even desktop-scale, machines."

The revolution in manufacturing would produce the "radical abundance" of the title, with small groups and individuals capable of producing an extraordinarily wide range of products without requiring large amounts of capital or long supply chains. The risks of social and political disruption are then examined. The disruptions that can be anticipated include "falling demand for conventional labor, resources, and capital in physical production, with the potential for cascading disruptive effects throughout the global economy", as well as disruptions in supply chains, trade, dependence, and the revaluation of assets (mineral resources and large industrial facilities, for example, will lose much of their value).

This would go together with an increase in surveillance capability and a potential nanotechnology arms race. The book recommends taking pre-emptive action at the international level to prepare for these disruptions.



01-Jun-13: Nanostart AG: Venture Capital Investments in Nanotech [475]
– Initiative

A key sign of a developing technology is interest from investment companies. Nanostart AG is an example of such a company, with extensive investments in various nanotechnology projects. Interestingly, their interests are not limited to more conventional nanotech projects, but extend to such speculative endeavours as space elevators.[476] This serves as a reminder of the potentially large profits available in nanotechnology. Thus it seems likely that when the technology matures sufficiently to cause increased risks, there will be many commercial entities heavily investing in the technology, which will make the process of regulation more contentious, possibly leading to "regulatory capture" [477] by these entities, with their interests represented rather than those of the broader community.

16-Dec-13: Nanotechnology: A Policy Primer, CRS report of Congress [478]
– Policy

Governmental and supra-governmental policies will be key to dealing with the dangers and destabilising influences of nanotechnology, through regulation, treaties, redistributive efforts or simply through preparing their populations for the change. And institutions such as the US Congress are keeping an eye on nanotechnology, in this case through the Congressional Research Service. This report, however, does not delve into the major risks of nanotechnology, but restricts itself to minor subjects such as the safety of nanomaterials and US competitiveness in that field. War, trade disruption and potential development and misuse of nano-replicators[479] are not discussed. This seems to reflect a certain lack of prioritisation and perhaps even a misplaced focus on the less important risks.

Source: http://upload.wikimedia.org/wikipedia/commons/thumb/b/be/XP002.jpg/1279px-XP002.jpg

3.3 Emerging risk

3.3.3 Artificial Intelligence

Artificial intelligence (AI) is the intelligence exhibited by machines or software, and the branch of computer science that develops machines and software with human-level intelligence.

Major AI researchers and textbooks define the field as "the study and design of intelligent agents", where an intelligent agent is a system that perceives its environment and takes actions that maximise its chances of success.[480]

3.3.3.1 Expected impact

Artificial Intelligence (AI) is one of the least understood global challenges. There is considerable uncertainty on what timescales an AI could be built, if at all, with expert opinion shown to be very unreliable in this domain.[481] This uncertainty is bi-directional: AIs could be developed much sooner or much later than expected.

Despite the uncertainty of when and how AI could be developed, there are reasons to suspect that an AI with human-comparable skills would be a major risk factor. AIs would immediately benefit from improvements to computer speed and any computer research. They could be trained in specific professions and copied at will, thus replacing most human capital in the world, causing potentially great economic disruption. Through their advantages in speed and performance, and through their better integration with standard computer software, they could quickly become extremely intelligent in one or more domains (research, planning, social skills...). If they became skilled at computer research, the recursive self-improvement could generate what is sometime called a "singularity", [482] but is perhaps better described as an "intelligence explosion", [483] with the AI's intelligence increasing very rapidly.[484]

Such extreme intelligences could not easily be controlled (either by the groups creating them, or by some international regulatory regime),[485] and would probably act in a way to boost their own intelligence and acquire maximal resources for almost all initial AI motivations.[486] And if these motivations do not detail[487] the survival and value of humanity in exhaustive detail, the intelligence will be driven to construct a world without humans or without meaningful features of human existence.

This makes extremely intelligent AIs a unique risk,[488] in that extinction is more likely than lesser impacts. An AI would only turn on humans if it foresaw a likely chance of winning; otherwise it would remain fully integrated into society. And if an AI had been able to successfully engineer a civilisation collapse, for instance, then it could certainly drive the remaining humans to extinction.

On a more positive note, an intelligence of such power could easily combat most other risks in this report, making extremely intelligent AI into a tool of great positive potential as well.[489] Whether such an intelligence is developed safely depends on how much effort is invested in AI safety ("Friendly AI")[490] as opposed to simply building an AI.[491]

If the returns from increased intelligence are low, intelligence explosions and extreme intelligence may not be possible. In that case, there would probably be an ecology of AIs of different levels of intelligence, performing different tasks. In this scenario, apart from the economic dislocation already noted, there is also the possibility of AI-enabled warfare and all the risks of the technologies that AIs would make possible.

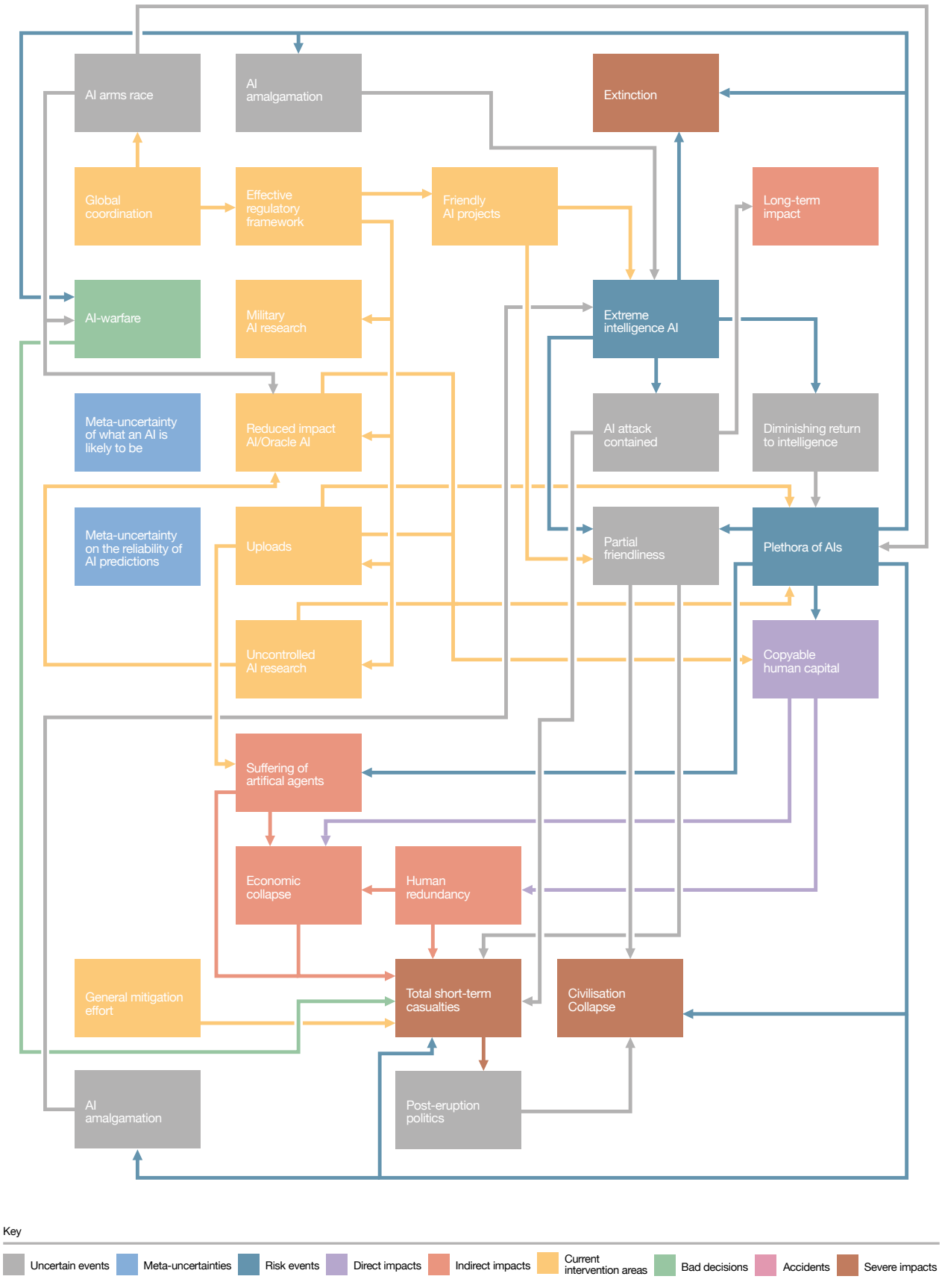
Source: http://commons.wikimedia.org/wiki/File:Artificial.intelligence.jpg

An interesting version of this scenario is the possible creation of "whole brain emulations," human brains scanned and physically instantiated - physically represented - in a machine. This would make the AIs into, what could be called, properly human minds, possibly alleviating a lot of problems.

3.3.3.2 Probability disaggregation

Five important factors in estimating the probabilities and impacts of the challenge:

1. The reliability of AI predictions.
2. Whether there will be a single dominant AI or a plethora of entities.
3. How intelligent AIs will become.
4. Whether extremely intelligent AIs can be controlled, and how.
5. Whether whole brain emulations (human minds in computer form) will arrive before true AIs.


AI arms race
AI amalgamation
Extinction
Global coordination
Effective regulatory framework
Friendly AI projects
Long-term impact
AI-warfare
Military AI research
Extreme intelligence AI
Meta-uncertainty of what an AI is likely to be
Reduced impact AI/Oracle AI
AI attack contained
Diminishing return to intelligence
Meta-uncertainty on the reliability of AI predictions
Uploads
Partial friendliness
Plethora of AIs
Uncontrolled AI research
Copyable human capital
Suffering of artifical agents
Economic collapse
Human redundancy
General mitigation effort
Total short-term casualties
Civilisation Collapse
AI amalgamation
Post-eruption politics
Key
Uncertain events
Meta-uncertainties
Risk events
Direct impacts
Indirect impacts
Current intervention areas
Bad decisions
Accidents
Severe impacts

1. The advantages of global coordination and cooperation are clear if there are diminishing returns to intelligence and a plethora of AIs, but less clear if there is a strong first mover advantage to the first group to produce AI: then the decisions of that first group are more relevant than the general international environment.

2. Military AI research will result in AIs built for military purposes, but possibly with more safeguards than other designs.

3. Effective regulatory frameworks would be very difficult without knowledge of what forms AIs will ultimately take.

4. Uncontrolled AI research (or research by teams unconcerned with security) increases the risk of potentially dangerous AI development.

5. "Friendly AI" projects aim to directly produce AIs with goals compatible with human survival.

6. Reduced impact and Oracle AI are examples of projects that aim to produce AIs whose abilities and goals are restricted in some sense, to prevent them having a strong negative impact on humanity.[493]

7. General mitigation methods will be of little use against intelligent AIs, but may help in the aftermath of conflict.

8. Copyable human capital – software with the capability to perform tasks with human-like skills – would revolutionise the economic and social systems.

9. Economic collapse may follow from mass unemployment as humans are replaced by copyable human capital.

10. Many economic and social set-ups could inflict great suffering on artificial agents, a great moral negative if they are capable of feeling such suffering.[494]

11. Human redundancy may follow the creation of copyable human capital, as software replaces human jobs.

12. Once invented, AIs will be integrated into the world's economic and social system, barring massive.resistance.

13. An AI arms race could result in AIs being constructed with pernicious goals or lack of safety precautions.

14. Uploads – human brains instantiated in software – are one route to AIs. These AIs would have safer goals, lower likelihood of extreme intelligence, and would be more likely to be able to suffer.[495]

15. Disparate AIs may amalgamate by sharing their code or negotiating to share a common goal to pursue their objectives more effectively.

16. There may be diminishing returns to intelligence, limiting the power of any one AI, and leading to the existence of many different AIs.[496]

17. Partial "friendliness" may be sufficient to control AIs in certain circumstances.

18 .Containing an AI attack may be possible, if the AIs are of reduced intelligence or are forced to attack before being ready.

19. New political systems may emerge in the wake of AI creation, or after an AI attack, and will profoundly influence the shape of future society.

20. AI is the domain with the largest uncertainties; it isn't clear what an AI is likely to be like.

21. Predictions concerning AI are very unreliable and underestimate uncertainties.

3.3.3.3 Main events during 2013

19-Mar-13: DARPA Sets Out to Make Computers That Can Teach Themselves [497]

– Policy

The amount of information stored in a human brain is extremely large. Similarly, the amount of information needed to perform adequately at complex human tasks is considerable – far more than is easily programmable by hand (the Cyc project,[498] for instance, started in 1984, aiming to rapidly formally codify all human common sense – and is still running). Thus the interest, in the field of machine learning, of algorithms that can teach themselves skills and knowledge from raw data. With the rise of "Big Data",[499] vast databases and increased computer power, there has been a flowering of applications of computer learning.[500] This has caught the eye of the Defense Advanced Research Projects Agency (DARPA), a research arm of the US defence department responsible for the development of new technologies. In this project, DARPA aims both to "enable new applications that are impossible to conceive of using today's technology" and to simplify machines so that non-experts can effectively use them and build applications for them. This most recent project confirms the interest of the military in artificial intelligence development.

25-Apr-13: Kurzweil plans to help Google make an AI brain [501]

– Initiative

The idea of creating a fully general AI, an AI that is capable of all tasks requiring intelligence, went into abeyance during the AI winter,[502] a period of reduced interest and funding in AI. The term AI itself fell into disfavour.[503] But recent AI successes such as Watson's triumph on "Jeopardy!" [504] (demonstrating a certain level of natural language recognition and processing) and Google's self-driving car[505] (demonstrating spatial awareness and movement) have revived interest in constructing a human-like mind in digital form. Kurzweil, hired by Google at the end of 2012, reveals in this interview his interest in doing just that. A notable feature of Kurzweil is his optimism about the consequences of creating AIs,[506] which could affect the level of precautions his team would include in its design.

13-Sep-13: Publication: "Responses to Catastrophic AGI Risk: A Survey" [507]

– Research

Since the recognition of the potential risk with AGI (Artificial General Intelligence),[508] various proposals have been put forward to deal with the problem. After arguing that uncertainty about a timeline to AI[509] does not translate into a certainty that AIs will take a long time, the paper analyses why AIs could be an existential risk. It argues that a trend toward automatisation would give AIs increased influence in society, as such systems would be easier to control, and there could be a discontinuity in which they gained power rapidly.[510] This could pose a great risk to humanity if the AIs did not share human values (intelligence and values are argued to be independent for an AI),[511] a task which seems difficult to achieve if human values are complex and fragile,[512] and therefore problematic to specify.

The authors then turned to analysing the AI safety proposals, dividing them into proposals for societal action, external constraints, and internal constraints. They found that many proposals seemed to suffer from serious problems, or to be of limited effectiveness. They concluded by reviewing the proposals they thought most worthy of further study, including AI confinement, Oracle AI, and motivational weaknesses. For the long term, they thought the most promising approaches were value learning (with human-like architecture as a less reliable but possibly easier alternative). Formal verification was valued, whenever it could be implemented.

01-Oct-13: Publication of "Our Final Invention: Artificial Intelligence and the End of the Human Era" by James Barrat, warning of the dangers of AI [519]

– Research,

In this book, James Barrat argues for the possibility of human-level AI being developed within a decade, based on the current progress in computer intelligence and the large sums invested by governments and corporations into AI research. Once this is achieved, the AI would soon surpass human intelligence, and would develop survival drives similar to humans (a point also made in Omohundro's "AI drives" thesis).[520] The book then imagines the competition between humanity and a cunning, powerful rival, in the form of the AI – a rival, moreover, that may not be "evil" but simply harmful to humanity as a side effect of its goals, or simply through monopolising scarce resources.

Along with many interviews of researchers working in the forefront of current AI development, the book further claims that without extraordinarily careful planning,[521] powerful "thinking" machines present potentially catastrophic consequences for the human race.

15-Oct-13: "Racing to the precipice: a model of artificial intelligence development" lays out the dangers of AI arms races [522]

– Research

AIs may be developed by different groups, each desiring to be the first to produce an artificial mind. The competitive pressure will be stronger the more powerful AIs are believed to be, thus maximising the danger in those situations. This paper considers an AI arms race,[523] where different teams have the option of reducing their safety precautions in order to perfect their device first – but running the risk of creating a dangerous and uncontrollable AI. In the absence of enforceable agreements between the teams, this dynamic pushes each to take on more risk than they would want (similarly to the "prisoner's dilemma"),[524] potentially causing an extremely damaging outcome.

The situation is improved if risk-taking makes little difference to speed of development, if the teams have reduced enmity between them, or if there are fewer teams involved (those last two factors also help with reaching agreements). Somewhat surprisingly, information has a negative impact: the outcome is safer if the teams are ignorant of each other's rate of progress, and even of their own.

24-Oct-13: Growing researcher awareness of the threat of artificial intelligence [525]

– Research

Much more effort is devoted to creating AI than to ensuring that it is developed safely.[526] Those working in developing AI could be motivated to minimise the extent their creation represented a potential danger.[527] It is therefore significant when a researcher focused on the danger of AI is invited to speak at a mainstream AI conference, as Dr. Anders Sandberg of the Future of Humanity Institute was, at the 23rd International Joint Conference on Artificial Intelligence in Beijing. He took part in a panel discussion entitled "The Future of AI: What if we succeed?", along with Joanna Bryson, Henry Kautz and Sebastian Thrun. He argued that though current AI research does not appear to directly lead to dangerous AIs, the time to design and implement safety measures is now. This is both because of the time needed to develop such safety measures, which could necessitate solving hard philosophical problems,[528] and because of the potential for sudden increases in AI skill and intelligence. Further, security precautions would be easier to implement if they were integrated into the design by the designers themselves (or by researchers intimately aware of the properties of the design). Further evidence of the increased awareness of risks was Stuart Russell's[529] joining of the board of the Cambridge Centre for the Study of Existential Risks (CSER).[530]

3.3 Emerging risk

3.3.4 Unknown Consequences

Uncertain risks represent the unknown unknowns in the family of global catastrophic challenges.

They constitute an amalgamation of all the risks that can appear extremely unlikely in isolation, but can combine to represent a not insignificant proportion of the risk exposure [531]

3.3.4.1 Expected impact

There are many different possible risks that seem individually very unlikely and speculative. Could someone develop a super-pollutant that renders the human race sterile? Could the LHC have created a black hole that swallowed the Earth? [532] Might computer games become so addictive that large populations will die rather than ceasing to indulge in them? [533] Could experiments on animals lift them to a level of intelligence comparable with humans? [534] Might some of the people sending signals to extra-terrestrial intelligences attract deadly alien attention? [535] What are the risks out there that we can't yet conceive of?

These risks sound unlikely and for many possibly ridiculous. But many of today's risks would have sounded ridiculous to people from the past. If this trend is extrapolated, there will be risks in the future that sound ridiculous today, which means that absurdity is not a useful guide to risk intensity.

Expert opinion provides some information on specific speculative risks. But it will tend to give them extremely low probabilities – after all, the risks are highly speculative, which also means the expert's judgement is less reliable.[536]

But in these situations, the main source of probability of the risk is not the quoted number, but the much greater probability that the experts' models and world views are wrong.[537] If marginal scientific theories predict large risks, the probability is concentrated in the likelihood that the theory might be correct.[538] Conversely, if many independent models, theories, and arguments all point in the direction of safety, then the conclusion is more reliable.

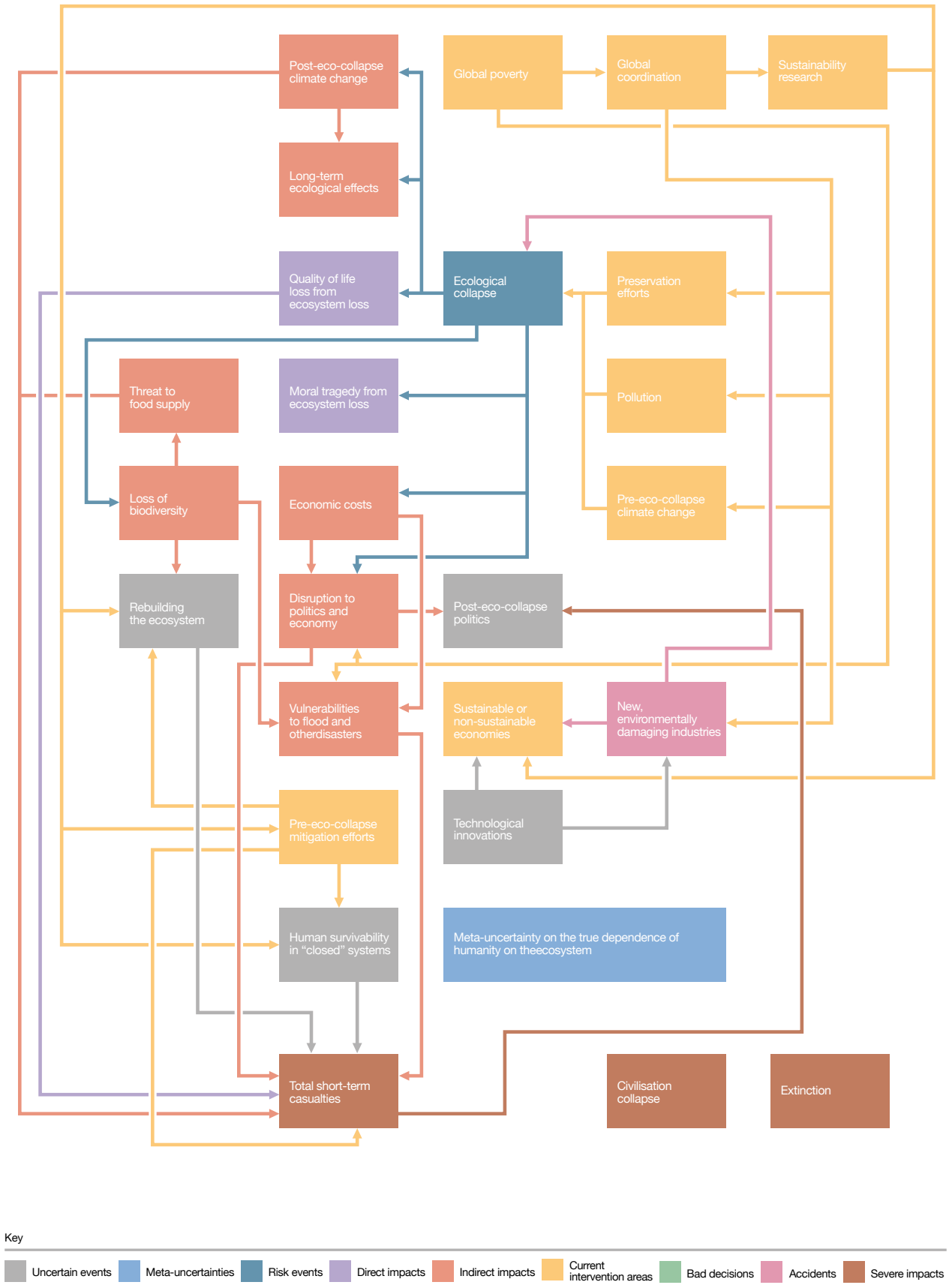
There are methods to estimate uncertain risks without needing to be explicit about them. One resolution to the Fermi paradox – the apparent absence of alien life in the galaxy – is that intelligent life destroys itself before beginning to expand into the galaxy. Results that increase[539] or decrease the probability of this explanation modify the generic probability of intelligent life (self-)destruction, which includes uncertain risks. Anthropic reasoning[540] can also bound the total risk of human extinction, and hence estimate the unknown component.

Non-risk-specific resilience and post-disaster rebuilding efforts[541] will also reduce the damage from uncertain risks, as would appropriate national and international regulatory regimes.[542] Most of these methods would also help with the more conventional, known risks, and badly need more investment.

3.3.4.2 Probability disaggregation

Five important factors in estimating the probabilities and impacts of the challenge:

1. Whether there will be **extensive research into unknown risks** and their probabilities.
2. The capacity to develop methods for **limiting the combined probability** of all uncertain risks.
3. The capacity for **estimating "out-of-model" risks**.
4. The **culture of risk assessment** in potentially risky areas.
5. Whether general, **non-risk-specific mitigation or resilience measures are implemented**.


Post-eco-collapse climate change
Global poverty
Global coordination
Sustainability research
Long-term ecological effects
Quality of life loss from ecosystem loss
Ecological collapse
Preservation efforts
Threat to food supply
Moral tragedy from ecosystem loss
Pollution
Loss of biodiversity
Economic costs
Pre-eco-collapse climate change
Rebuilding the ecosystem
Disruption to politics and economy
Post-eco-collapse politics
Vulnerabilities to flood and otherdisasters
Sustainable or non-sustainable economies
New, environmentally damaging industries
Pre-eco-collapse mitigation efforts
Technological innovations
Human survivability in "closed" systems
Meta-uncertainty on the true dependence of humanity on theecosystem
Total short-term casualties
Civilisation collapse
Extinction
Key
Uncertain events
Meta-uncertainties
Risk events
Direct impacts
Indirect impacts
Current intervention areas
Bad decisions
Accidents
Severe impacts

1. Smart sensors and surveillance could detect many uncertain risks in the early stages, and allow researchers to grasp what is going on.

2. Proper risk assessment in domains where uncertain risks are possible could cut down on the risk considerably.

3. Global coordination would aid risk assessment and mitigation.

4. Specific research into uncertain and unknown risks would increase our understanding of the risks involved.

5. General mitigation efforts are mostly general resilience building.

6. Some institutions may deliberately pursue dangerous technologies or experiments, or may convince themselves that their research is not dangerous.

7. Unforeseen accidents could be the trigger for many uncertain risks.

8. The amount of direct casualties varies wildly depending on the risk involved.

9. The disruptions to the world's economic and political system vary wildly depending on the risk involved.

10. The uncertain risk may have other disruptive effects (such as loss of trust in certain technologies).

11. The long-term impact varies wildly depending on the risk involved.

12. The world's political structure, after an unknown risk is triggered, will determine whether humanity improves or worsens the situation.

13. Some methods (such as considering the Fermi paradox) may bound the total probability of destructive uncertain risks, but these are very speculative.

14. Trying to estimate unknown or out of model risks is by definition very difficult and uncertain.

3.3.4.3 Main events during 2013

28-Mar-13: Paper on Adaptation to and recovery from global catastrophes in general [543]

– Research

One approach to dealing with uncertain risks is to build general adaptation and recovery methods that would be relevant to a wide class of potential disasters. This paper notes the absence of published research in this area,[544] and seeks to begin to fill the gap. It identifies methods for increasing survivor resilience and promoting successful adaptation and recovery, even for isolated communities. It recognises that the process is highly complex, and needs further research.

28-Mar-13: Paper Evaluating Methods for Estimating Existential Risks [545]

– Research

It would be advantageous to have a rigorous approach for estimating severe risks, including uncertain and unknown ones. This paper reviews and assesses various methods for estimating existential risks, such as simple elicitation; whole evidence Bayesian; evidential reasoning using imprecise probabilities; Bayesian networks; influence modelling based on environmental scans; simple elicitation using extinction scenarios as anchors; and computationally intensive possible-worlds modelling.[546] These methods can be applied rigorously to uncertain risks, assessing them in the same way as more standard risks. Influence modelling based on environmental scans[547] can even suggest some new as yet unknown risks.

01-Aug-13: The Fermi paradox provides an estimate of total existential risk (including uncertain risks) [548]

– Research

The Fermi paradox is the seeming contradiction between the apparent ease with which intelligent life could arise in the galaxy, and the lack of evidence of any such life.

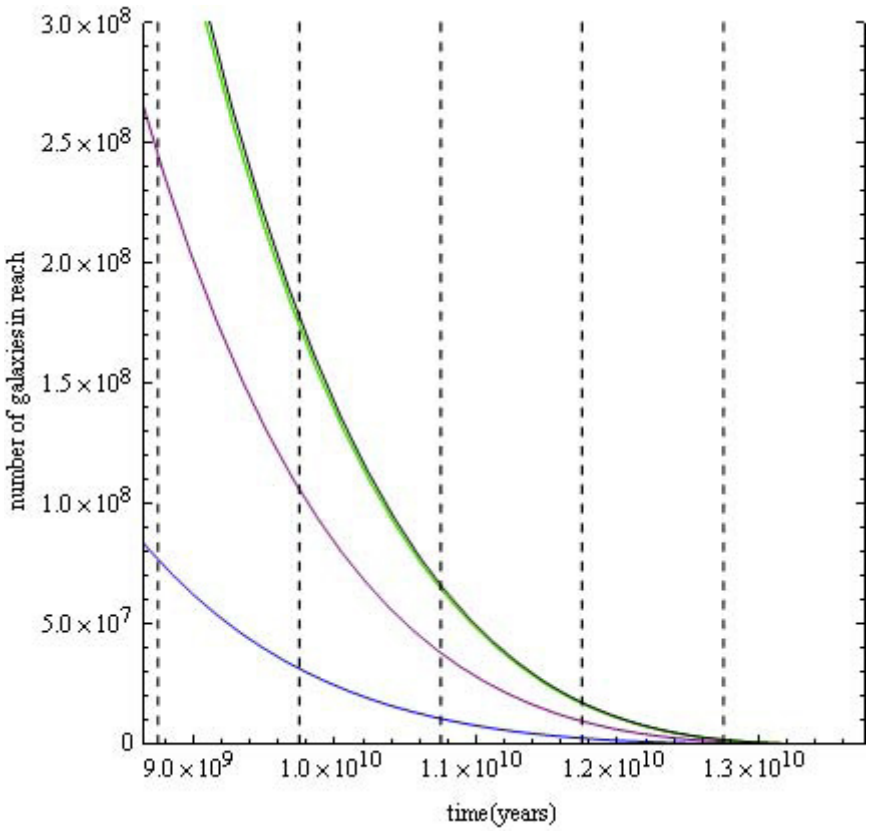
Many explanations have been proposed to resolve the paradox,[549] one of which is relevant to existential risks: the "Late Great Filter" explanation.[550] This posits that intelligent life is inevitably destroyed before it can expand through the galaxy.

Such an explanation gives a bound to existential risk from all sources, including uncertain risks.

This paper demonstrates the relative ease with which a space-faring civilisation could cross between galaxies.

Combined with recent evidence that the majority of Earth-like planets formed before the Earth,[551] this makes the absence of visible intelligent life more inexplicable, and worsens the Fermi paradox, increasing the probability of a Late Great Filter and thus of existential risk from all sources.

Figure 23: Number of galaxies that can reach us with speeds of 50%c, 80%c, 99%c and c, from different starting moments [552]



01-Nov-13: Top conglomerates spearhead creation of private sector disaster response body [553]
– Initiative

One of the most effective tools against uncertain risks is to adopt general disaster recovery measures. Anything that enables the preservation of resources or knowledge and the rapid reconstruction of key infrastructure will be of use against a wide variety of risks. Though governments and supra-governmental organisations play a vital role in this, it would be beneficial to get the private sector, with its funds and its expertise, involved too. The private sector has played a key role in recovery from many disasters (such as the Japanese 2011 earthquake/ tsunami).[554] This news report shows that the private sector aims to take on a larger role in disaster relief in the Philippines. More importantly, the key players aim for the creation of a private sector disaster response body, so as to have a better organised private sector response during disasters. This is significant as it disperses disaster recovery expertise to a wider group of individuals, and suggests that private companies may be alternate entities capable of providing relief after a major disaster. Thus preparations for post-disaster recovery could include building up private sector capacity as well as other measures.

3.4 Global Policy risk

3.4.1 Future Bad Global Governance

"Global governance refers to the way in which global affairs are managed. As there is no global government, global governance typically involves a range of actors including states, as well as regional and international organisations.

However, a single organisation may nominally be given the lead role on an issue." [485]

Often global governance is confused with global government, but they are two very different things. Global governance is just a term to describe the way global affairs are managed, or not managed. Global government is the idea that the world should be run like a country with a government. The global governance system will inevitably have pros and cons, depending on the political decisions that are made.

3.4.1.1 Expected impact

This section looks at global governance disasters. Though all the risks in this report can be exacerbated by poorly chosen policy decisions, this classification contains those problems that arise almost exclusively from bad policy choices.

There are two main divisions in governance disasters: failing to solve major solvable problems, and actively causing worse outcomes. An example of the first would be failing to alleviate absolute poverty.[556]

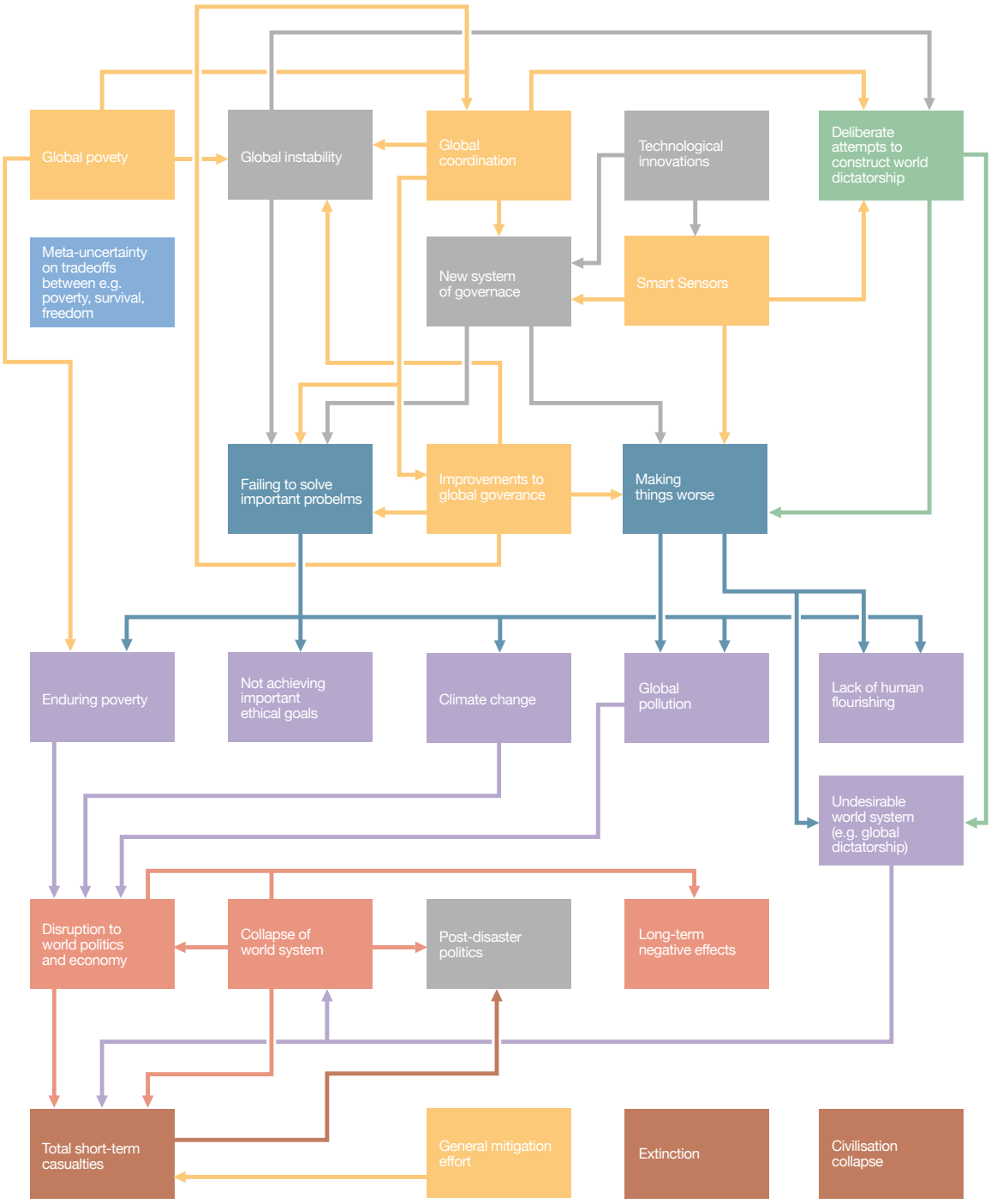
An example of the second would be constructing a global totalitarian state.[557] In general, technology, political and social change may enable the construction of new forms of governance, which may be either much better or much worse.

These examples immediately illustrate two issues with governance disasters. First, the task of estimating their probability is difficult. Long-term political predictions are of questionable validity and subject to strong biases,[558] especially where strongly-held values are concerned.[559] Second, the impact of these governance disasters depends to a large extent on subjective comparative evaluations. It is not impartially obvious how to rank continued poverty and global totalitarianism versus billions of casualties or civilisation collapse.[560] The long term impact needs also to be considered: how will poverty and global governance change? If there are many generations ahead of us, then the long term state of humanity's policy[561] becomes much more important than the short term one.

3.4.1.2 Probability disaggregation

Five important factors in estimating the probabilities of various impacts:

1. How the severity of non-deadly policy failures can be compared with potential casualties.
2. Whether poor governance will result in a collapse of the world system.
3. How mass surveillance and other technological innovations will affect governance.
4. Whether there will be new systems of governance in the future.
5. Whether a world dictatorship may end up being constructed.



Key

Uncertain events | Meta-uncertainties | Risk events | Direct impacts | Indirect impacts | Current intervention areas | Bad decisions | Accidents | Severe impacts

1. Global coordination between nations is essential for building a good global governance system – but also essential for building a bad one.

2. Global poverty is one of the important problems that are being only partially solved by current policies. In turn, it can contribute to global instability, worsening likely governance outcomes.

3. Smart sensors and mass surveillance can contribute to new systems of governance, but also to large-scale dictatorships.

4. The global system of governance consists of the UN and a wide variety of bilateral or multilateral agreements and norms, constructed mainly according to national self-interests. Thus significant improvements to global governance are currently possible.

5. General mitigation efforts against governance disasters are tricky – most mitigation efforts are the results of governance decisions! However, some efforts can be made – for instance, an increase in recognised human rights across the globe could militate against certain pernicious governance directions. These efforts are of a very different nature to mitigating other risks.

6. Some groups may deliberately seek to construct a world dictatorship, either through self-interest or because they believe it would be the best design for global governance.

7. Undesirable world systems (such as global dictatorships) could result from a worsening of global governance.

8. Many value systems do not distinguish between action and inaction, so a global system that didn't positively encourage human flourishing would be almost as pernicious as one that blocked it.

9. Global pollution is a problem requiring solutions at the global governance level.

10. Climate change is a problem requiring solutions at the global governance level.

11. Various ethical systems have desirable goals that could be achieved in theory, but would not be achieved under suboptimal governance.

12. It would be a tragedy if absolute poverty were to endure over the generations to come, especially if this outcome were avoidable.

13. A collapse of the world system, for any reason (including revolution) is the most direct way a governance disaster could result in mass casualties.

14. Governance decisions taken at the global level have a high potential to cause disruptions to the world's political and economic systems.

15. Bad governance at the global level may not be susceptible to improvements and could cause problems for a considerable amount of time.

16. Technological innovations could allow completely new models of government, but could also facilitate surveillance dictatorships.

17. Global instability could result in more pernicious systems of governance, as well as an increased failure to solve important problems.

18. New systems of governance could be developed, using modern communication technology for instance.

19. The political landscape after a disaster will be important in determining whether governance disasters could cause civilisation collapses or mass casualties.

20. How to compare enduring poverty, actual casualties, and repressive governance is a question of values and not just of direct comparison of lives lost.

3.4.1.3 Main events during 2013

15-Feb-13: Existential risk reduction as a global priority [562]

– Research

In this paper Nick Bostrom, the director of the Future Humanity Institute, lays out the case for making existential risk reduction a global priority. Existential risks (Xrisks) are the highest category of negative impact in this report, those that threaten the entire future of humanity. The policy implications of the paper are:

– Existential risk is a concept that can focus long-term global efforts and sustainability concerns.
– The biggest existential risks are anthropogenic and related to potential future technologies.
– A moral case can be made that existential risk reduction is strictly more important than any other global public good.
– Sustainability should be rethought in dynamic terms, as aiming for a sustainable trajectory rather than a sustainable state.
– Some small existential risks can be mitigated today directly (e.g. asteroids) or indirectly (by building resilience and reserves to increase survivability in a range of extreme scenarios) but it is more important to build capacity to improve humanity's ability to deal with the larger existential risks that will arise later in this century. This will require collective wisdom, technology foresight, and the ability when necessary to mobilise a strong global coordinated response to expected existential risks.
– Perhaps the most cost-effective way to reduce existential risks today is to fund analysis of a wide range of existential risks and potential mitigation strategies, with a long-term perspective.

If this paper is right, a general lack of focus on existential risks by governments and other agents can be considered a governance disaster in itself.

19-Apr-13: Multidimensional poverty index diminishes in 18 out of 22 analysed countries [563]

– Event

Of 22 countries for which the Oxford Poverty and Human Development Initiative analysed changes in MPI (Multidimensional Poverty Index) poverty over time, 18 reduced poverty significantly.

This confirms other studies, by the World Bank[564] and others:[565] poverty reduction is possible, and has been successfully implemented in many countries.

05-Jun-13: Guardian leaks NSA spying programme [566]

– Initiative

A significant event was the revelation by Edward Snowden of the extent of the NSA's surveillance programme. This included the mass recording and mining of data across the United States and the interception of foreign politicians' data.

The revelations caused great controversy[567] and raised questions about the NSA's surveillance oversight.[568] The episode established that discrete mass surveillance – an important component of potential

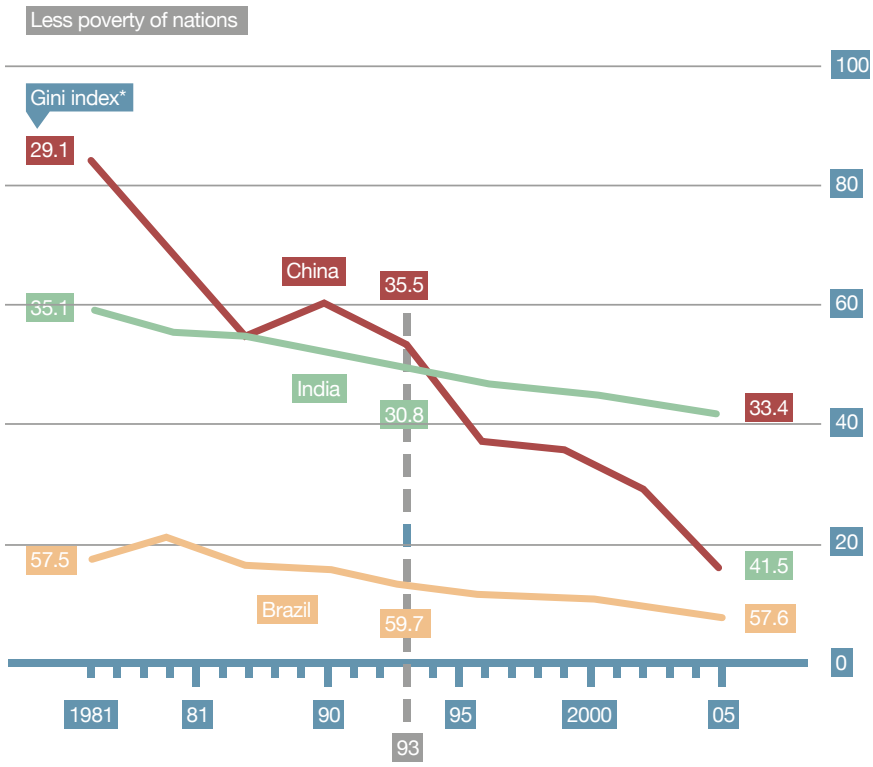


Figure 24: Less poverty of nation - Population living below $1.25 a day at 205 Purchasing-pover parity, %
* 0=absolute equality, 100=absolute inequality
Source: Economist, originally World Bank, http://www.economist.com/node/14979330

totalitarianism – was already possible using current technology and political organisation.

14-Jun-13: UNDP-UNEP Poverty-Environment Initiative Launches New Five-Year Phase to Meet Growing Demand from Member States [569] – Policy

To reduce poverty in the future, it is important to maintain and extend past trends in poverty mitigation. The United Nations' Poverty-Environment Initiative (PEI), launched in 2008, has had a number of success stories from Uruguay[570] to Malawi.[571] Due to increased demand from member states, the programme has been extended for another five years, 2013-2017, and may add countries such as Myanmar, Mongolia, Indonesia, Albania, Peru and Paraguay. Such programmes demonstrate that the bureaucratic/policy side of poverty reduction is supported by an international infrastructure with a strong emphasis on assessments. The effect of such approaches on overall poverty will depend on the interplay between these policies and the other side of poverty reduction, economic growth[572] and trade.[573]

4. Relations between global risks

"We have some idea what might happen if, in the face of other pressing global challenges, we divert our focus from making systemic improvements in public health and veterinary services — and that prospect is frightening."

The World Bank [574]

Two things make the understanding of the relation between the global risks particularly important.

1. Impacts: The global risks are interconnected in different ways. Often the situation can be described as a set of dominoes: if one falls, many others follow. Even small impacts can start a process where different challenges interact. Higher temperatures due to global warming can result in the spreading of pandemics which increase tensions between countries, and so on.

2. Specific measures to address a risk: Global risks often require significant changes in our current society, from how we build cities to how food is produced and provided. Such significant changes will result in situations where measures to reduce the risk in one area affect the probability and/or the impact in other areas. Depending on the measure chosen to reduce the risk, and other complementary measures, the effect can be positive or negative.

4.1 General relations between global risks and their potential impacts

Relations between global risks is an area where surprisingly little work is being done. Most research focuses on individual or closely related groups of challenges. Organisations working on global challenges are almost always working on individual risks. The initial overview below is based on individual studies where different relations are analysed , but no work has been identified where the relations between all twelve challenges have been analysed.

A risk that is natural to start with is future bad global governance, as all other global challenges exacerbate governance disasters,[575] and all other global challenges can potentially be exacerbated by governance disasters. A well functioning global governance system is therefore a key factor to address global catastrophic risks.

Conversely, avoiding governance disasters improves all risks, as better institutions are better able to mitigate risks. Governance disasters directly increase the problems of climate change (through a lack of coordination between countries), the risk of nuclear war (by stoking conflict between nuclear powers) and global system collapse (by weakening global responses to systemic risks). All risks exacerbate global system collapse, by putting extra stress on an interconnected system.[576] Conversely, a resilient governance system is better able to cope with all risks, and a collapsed global system is more vulnerable to all risks.

Nuclear war,[577] asteroid impacts[578] and super-volcanoes[579] have direct impacts on the climate, and, through that, on the ecosystem.[580]

The kinds of mitigation efforts capable of containing the damage from a super-volcano would most likely be effective against asteroid impact damage, because of the similar nature of the impacts. The converse is not true, since one major method of reducing asteroid impact – space-based deflection[581] – would have no impact on super-volcano risk.

Solving climate change would help reduce current ecological pressure.[582] International agreements to reduce ecological damage could be extended to combating climate change as well, by establishing structures for international collaboration and encouraging resource-efficient solutions . Climate change also creates conditions more suitable for the spread of pandemics.[583] Measures to combat global pandemics, such as strengthened outbreak coordination and statistical modelling,[584] could be used to combat synthetic pathogens as well.

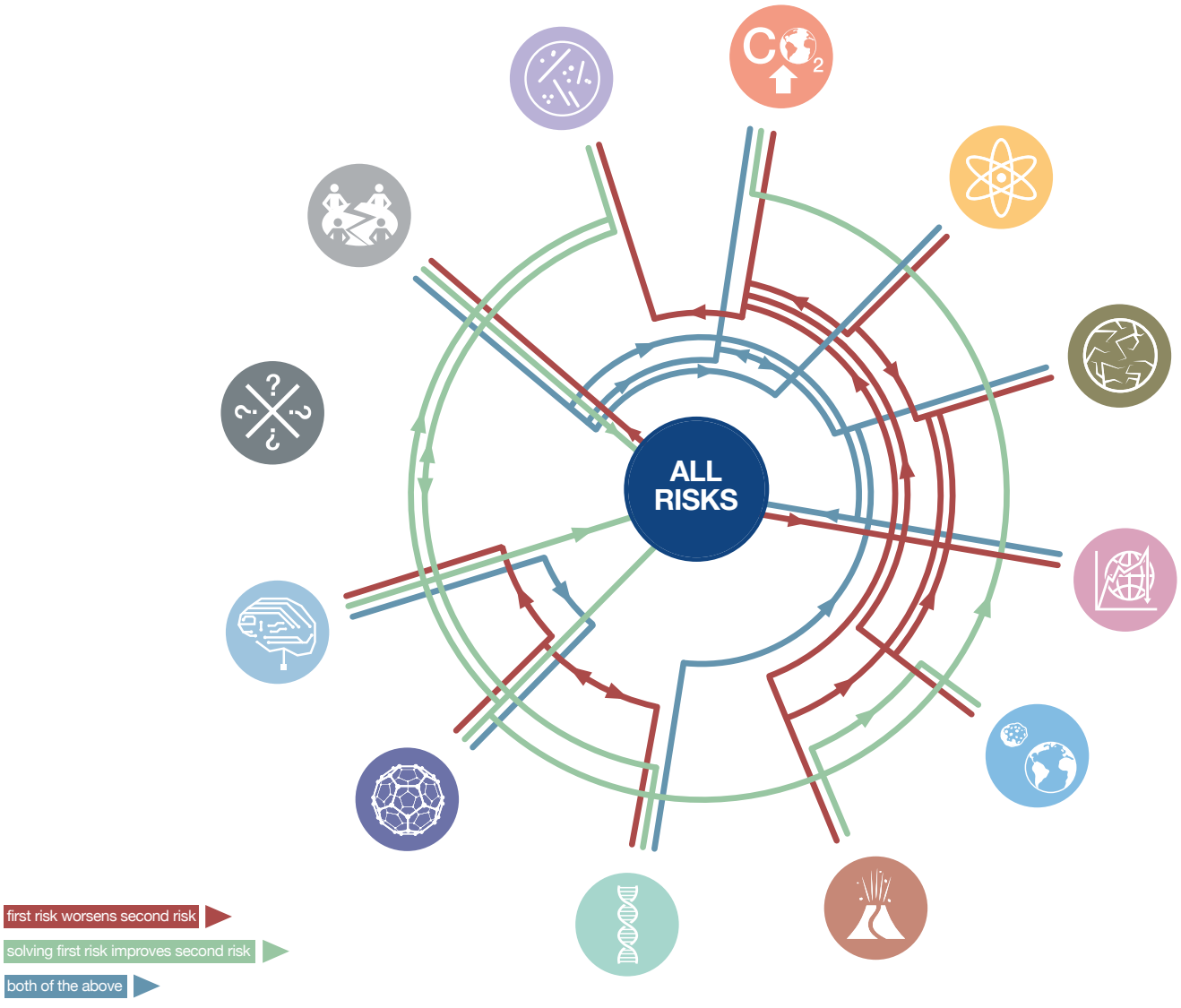
If a safe artificial intelligence is developed, this provides a great resource for improving outcomes and mitigating all types of risk.[585] Artificial intelligence risks worsening nanotechnology risks, by allowing nanomachines and weapons to be designed with intelligence and without centralised control, overcoming the main potential weaknesses of these machines[586] by putting planning abilities on the other side.

Conversely, nanotechnology abilities worsen artificial intelligence risk, by giving AI extra tools which it could use for developing its power base.[587] Nanotechnology and synthetic biology could allow the efficient creation of vaccines and other tools to combat global pandemics.[588] Nanotechnology's increased industrial capacity could allow the creation of large amounts of efficient solar panels to combat climate change, or even potentially the efficient scrubbing of CO2 from the atmosphere.[589]

Nanotechnology and synthetic biology are sufficiently closely related [590] (both dealing with properties on an atomic scale) for methods developed in one to be ported over to the other, potentially worsening the other risk. They are sufficiently distinct though (a mainly technological versus a mainly biological approach) for countermeasures in one domain not necessarily to be of help in the other.

Uncontrolled or malicious synthetic pathogens could wreak great damage on the ecosystem; conversely, controlled and benevolent synthetic creations could act to improve and heal current ecological damage.

There are many secondary effects that are not covered here. Increasing nuclear power could for instance improve the outlook for climate change,[591] while increasing the risk of proliferation[592] and thus of nuclear war. There are many such effects between various strategies for addressing different risks, but they are specific enough for there to be no simple arguments of the type which says that mitigating risk X worsens risk Y.



4.2 Specific relations between global risks

In parallel with work to increase our understanding about the general relations between global risks, work to identify more specific relations should also be initiated. This is an area where many pieces of research exist. But very little work has been done to combine them and assess different strategies to address specific global risks and understand how these strategies will affect other global risks. It is important to distinguish between two different kinds of specific relations.

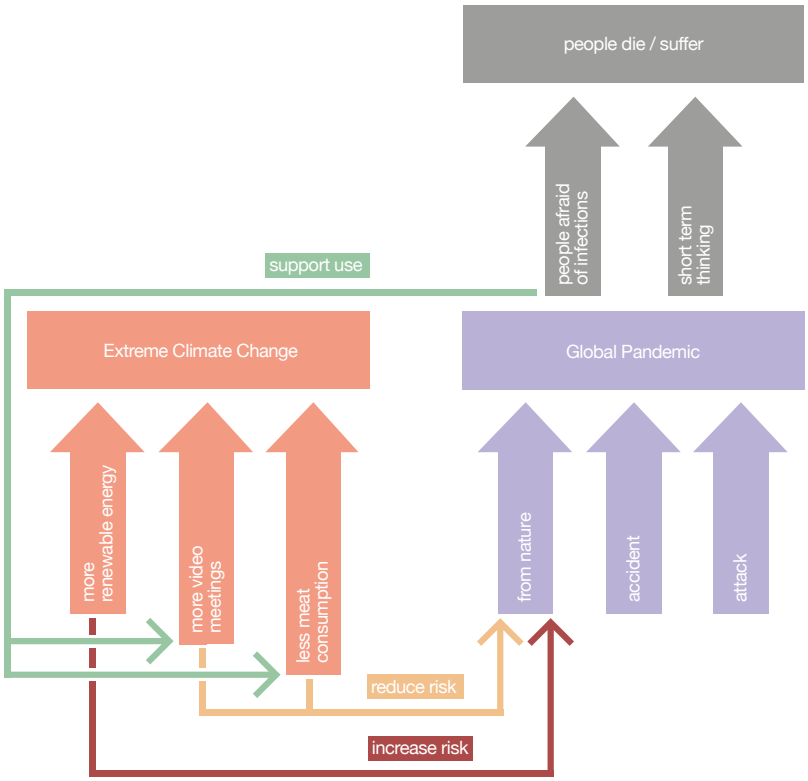
First, there are solution strategies for one global risk and the ways it affects other global risks. For example, using videoconferences can reduce the probability of pandemics by reducing unnecessary travel. On the other hand, unsustainable use of bio-energy could increase spillover opportunities when a zoonosis (a disease transmitted from animals to humans) increases the spread of pandemics due to an increased number of contacts between humans and infected animals in forests around the world.[593]

Second, how society reacts to the very threat of different risks can affect other challenges. For example, if people are afraid of pandemics they might use more video meetings and in that way help reduce carbon emissions.

Attempts to develop solutions for specific global challenges should assess their impacts, positive and negative, on other challenges. In order to better understand the relations between different global challenges work could start to analyse similarities and differences.

Below is an example of an overview of how different global challenges can be plotted depending on the technical difficulty of reducing the risk and the difficulty of collaborating to reduce it.

An international initiative should start to achieve better understanding of the relations between global challenges in order to ensure synergies and avoid strategies that will undermine other challenges.



5. Probabilities and uncertainties – an initial overview

"Uncertainty is an uncomfortable position. But certainty is an absurd one."

Voltaire

During the process of identifying risks that could have an infinite impact it became evident that the most common question among people interested in global challenges is this: "How probable is it that this impact will ever happen?" For those with expert knowledge in one area the first question is often: "How does the probability and magnitude of impact in this area compare with the probability and magnitude of impact in other areas?" Finally, those who have tried to estimate probabilities for global challenges ask: "What is the status of knowledge in other areas compared to mine?"

These are all very important questions, and this chapter is not an attempt to answer them. But, as there is no organisation, process or report that has provided an overview of quantified assessment for global challenges with potential infinite impact, the chapter does try to present the current state of knowledge in order to inspire further work.

It is easy to argue that it is too difficult, or even impossible, to assess the probabilities that are at all meaningful for the risks in this report, and therefore to exclude them. There are many good reasons for not trying, including significant uncertainty in almost all steps of the assessment. Not only do great uncertainties exist for all the risks, but the difficulties of estimating probabilities are also very different. At one end of the spectrum the probability of a nuclear war can change dramatically from one day to another due to political decisions. Much of the uncertainty is related to psychological assumptions of how different individuals will react under stress.

At the other end of the spectrum there is AI, where there is not even a generally accepted understanding of the possibility of the impacts capable of creating the risks covered in this report. There are challenges with very much data, including asteroids, and other challenges with very little relevant data, such as bad future global governance.

Obviously the risks also share a number of characteristics: they all have potentially extreme outcomes and have never been experienced before. The possibility of studying series of data, exploring how the outcome will change with incremental changes in input data, and testing conclusions on similar events are just a few examples of things that in most cases cannot be done. Estimating probabilities in traditional ways is therefore very difficult.[594]

However, as the current lack of interest in global risks with potentially infinite impacts may in part be due to the lack of actual numbers, the best estimates that could be found are presented below with explanations. These estimates are only an attempt to assemble existing estimates in order to encourage a process to improve these numbers.

These estimates range from rigorous calculations based on large amounts of high-quality data (asteroids) to guesstimates by interested experts (AI). The result is that some have a more rigorous methodology behind them, and others should be taken with a large grain of salt, but all are still very rough estimates. As science progresses they will be updated. It is even possible that some will change by orders of magnitude. But instead of no estimate at all, we now have an initial reference that we hope will trigger a discussion and collaboration that will help improve what we have already.

As many of the challenges are long-term and require early action to be avoided or mitigated the probability is provided for the next 100 years, instead of the annual probability that is often provided. The reason for this is that a 100-year perspective helps us understand that even relatively small probabilities can become significant over a century. Say that it is a one in 100 probability (1%) for an impact to occur. Over a century there is a 63.4% probability of one or more such impacts.[595] Further, structures that need to change require us to look beyond the immediate and incremental changes that most discussions focus on today.

Structure of the probability estimates
As the different challenges are very different and the status of probability estimates varies significantly, the initial probability numbers are provided together with estimates regarding:

1. The understanding of sequence.
   This is an estimation of how well the sequence from today to a possible infinite impact is understood. At one extreme all the different paths from today to an infinite impact are understood. At the other extreme, there is only a theoretical idea that is coherent and does not break any natural laws. In the latter case there would be no understanding of how it is possible to get from where we are today to an infinite impact. A sequence is required to calculate an estimate instead of only having educated guesses.
2. Data availability.
   This is an estimate of the amount of data available to make probability assessments on all relevant steps of the sequence. In some areas a lot of hard-to-get data is needed to make an assessment (e.g a global pandemic); in other areas the data is related to secret and/or psychological factors (e.g. large-scale nuclear war). In others relatively little data is needed (asteroids), or a lot has been done to gather data (e.g. climate change).
3. Existing probability estimates
   form an estimate of the kind of uncertainty that exists. This obviously depends on understanding of sequence and data availability, but it also depends on resources and interest in communicating with the rest of the world.

The estimates below are preliminary, but a sound risk approach requires stakeholders to begin to include them in strategic assessments.

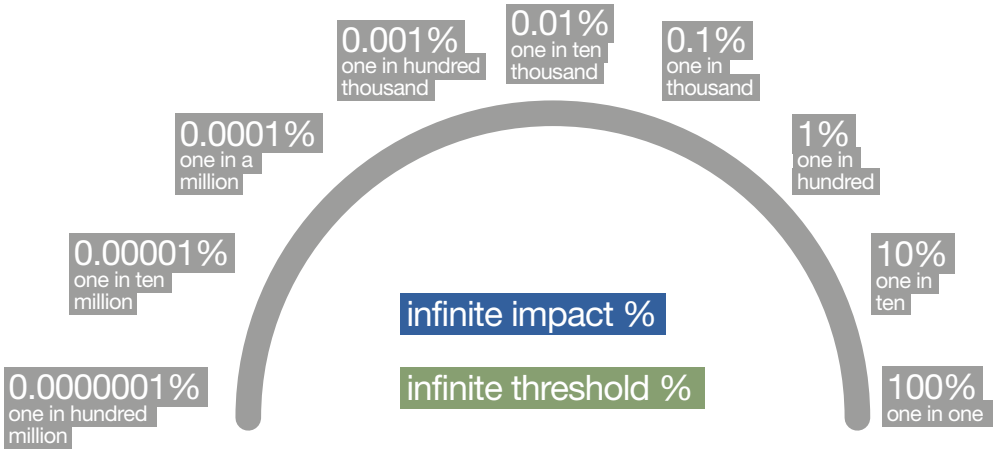
One group in particular is of interest and that is actuaries, the professionals who deal with the financial impact of risk and uncertainty.

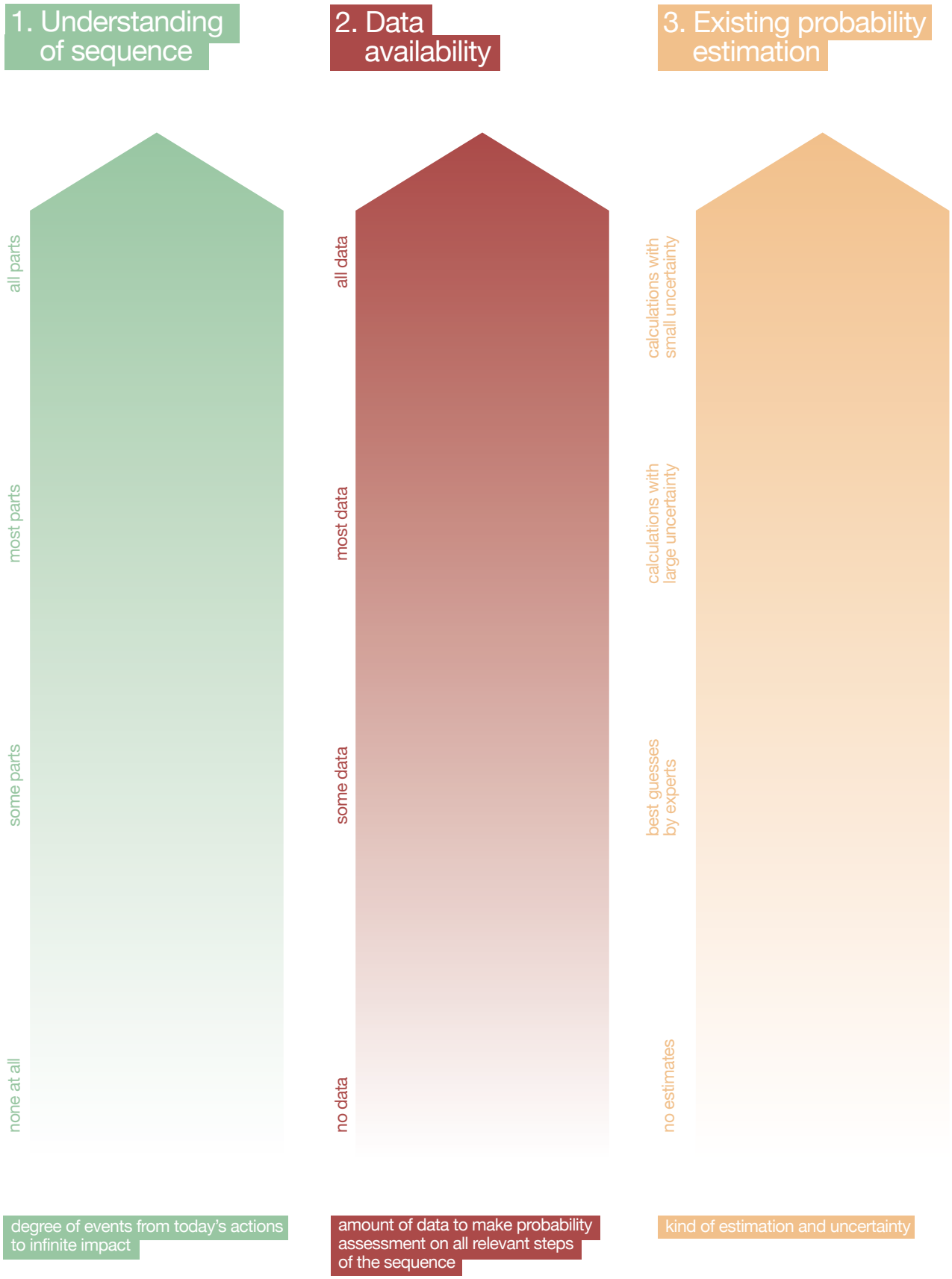
One of the key guiding rules they follow is to ensure a capital adequacy at a 1-in-200 level.

This rule, which is included in for example ICA[596] and Solvency II,[597] provides an opportunity to discuss risks with a possible infinite impact.

One contribution could be to discuss the pros and cons with different definitions of the 1-in-200 level. For example one definition is that "each company holds enough capital to withstand the events of the next one year with a probability of 199 out of 200." [598] This would exclude many of the risks in this report and could even result in the risks increasing, as the time perspective is so short. Investments could help reduce short-term risks at the same time as they increase long-term risks.

Another definition is that "a company should hold enough capital to be able to withstand a 'reasonably foreseeable' adverse event".[599] This highlights the challenge of determining what "reasonably foreseeable" is. Hopefully all the risks in this report could be included on such a list. Then the questions would be what we can do about it.

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Extreme Climate Change

Extreme climate change is one of the risks where global research collaboration has taken place on a significant scale.

The IPCC process is an unprecedented scientific achievement that has helped provide a unique level of understanding for such a complex area. Even so, the understanding of tipping points and collapses is still rudimentary. From a risk perspective it is important to know that many factors that could result in infinite impacts are excluded from most studies, for example the rapid release of methane clathrates.[600] Similarly, significant uncertainty exists about political decisions in many countries, about the implementation of new solutions and about what lifestyles will dominate.

The IPCC process ensures that data is widely available and of good quality, thanks to intensive peer review in the natural science area. Estimates of political and technological development exist, but they are more rudimentary compared to the natural science.[601]

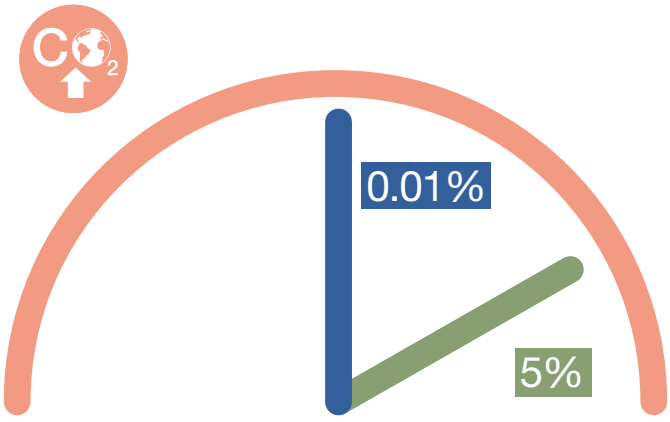
With such a high-profile area there are also a number of quantified estimates in key areas such as emissions trajectories, climate sensitivity, impacts and thresholds that allow for approximations of probabilities. But only a few estimates exist that provide probability assessments, as there is a tendency to use scenarios instead.

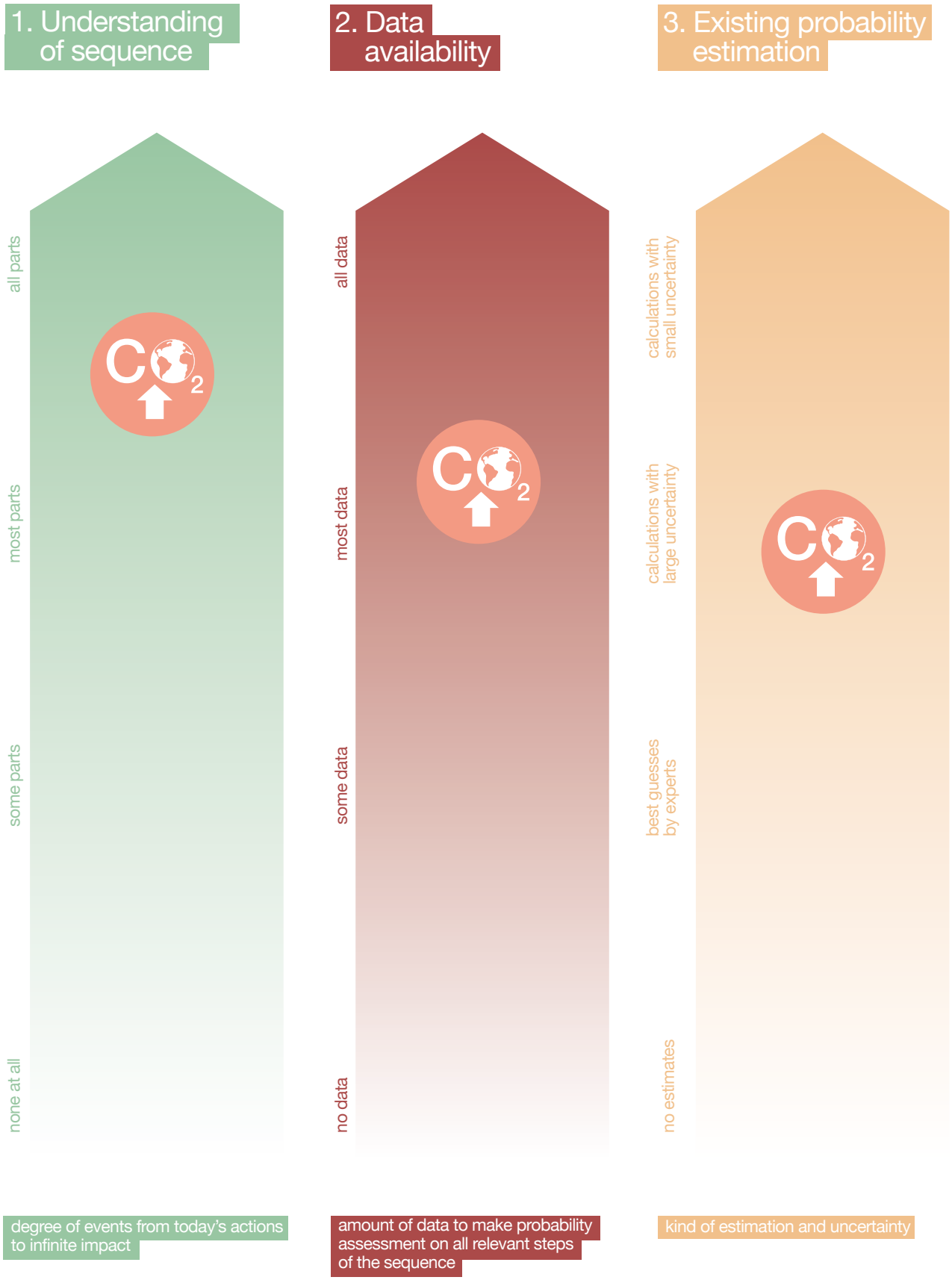
One aspect that makes climate change different from all other risks is that the time from initial action to impact is very long. The great uncertainty is where the threshold lies where the planet begins to emit greenhouse gases that start irreversible feedbacks.

Most models indicate that it will be decades before the Earth reaches equilibrium, and some impacts, like sea-level rise, will happen over millennia.[602] This long interval between action and impact means the probability of climate change is expressed on a 200-year timescale, compared with 100 years for the other challenges.

Based on available assessments[603] the best current estimate for extreme climate change in the next 200 years is:

5% for infinite threshold,
0.01% for infinite impact

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Nuclear War

Nuclear war is the risk that started the work with scientific assessments related to infinite impact.[604]

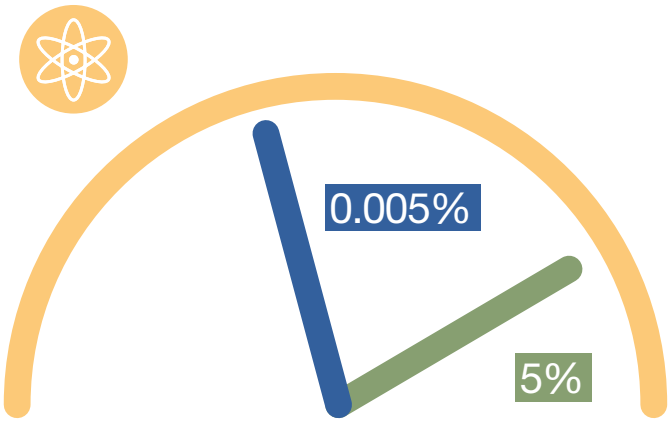
The understanding of the sequence is relatively well known. Still, the fact is that the impact will depend significantly on how serious the nuclear winter will be as the result of a war (if there is any nuclear winter at all). The probability of a nuclear winter will depend on when during the year the war happens, and what the weather is during this time. The result is that the probability of an infinite impact has an inherent uncertainty and can be estimated only once a war has already started.

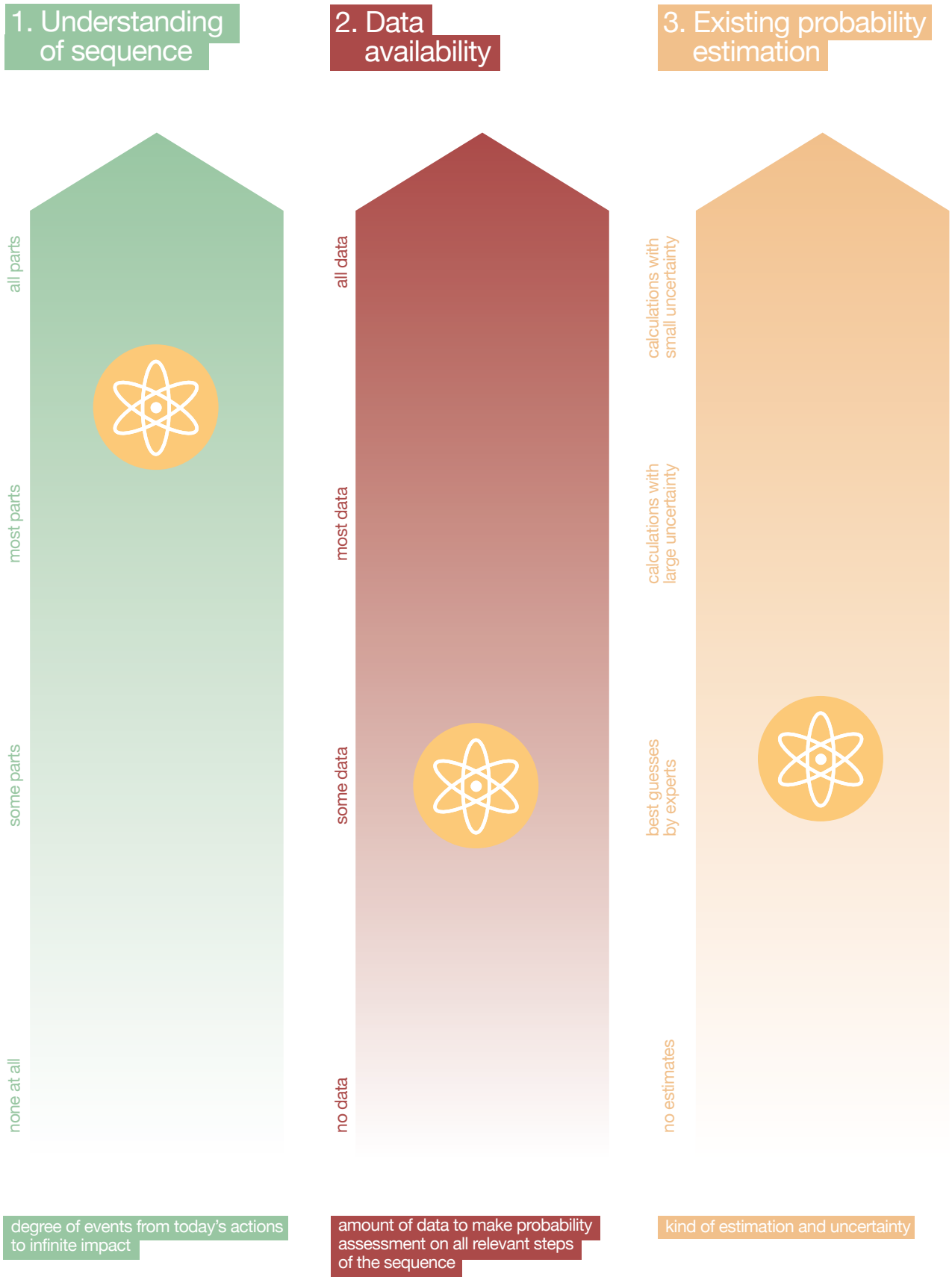
The data availability is relatively low as much of the probability is decided by factors that are secret (e.g. the targets for nuclear weapons). It depends on knowledge that by definition is unavailable (no nuclear explosions, for example, have taken place in a modern city); on human factors (e.g. stress tolerance and aggressive tendencies among those who will have to decide whether or not to launch nuclear weapons); and on the effectiveness of current policies (e.g. how efficient current deterrence policies are). The fact that climate change research has provided better scientific understanding of the probability and nature of a nuclear winter, thanks to better climate modelling, is worth noting as it shows how research programmes on different global challenges can be mutually supportive.[605]

There are some estimates of key aspects, such as the probability of accidental initiation of a nuclear war, but few estimates of the probability of a full-scale nuclear war.

Based on available assessments[607] the best current estimate for nuclear war in the next 100 years is:

5% for infinite threshold,
0.005% for infinite impact

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Global Pandemic

On a general level the sequence, or rather sequences, for a pandemic are relatively well-known. The challenge here is that there are so many different scenarios that it is very difficult to calculate all the different possibilities even if the sequence is well-known. Compared with climate change where GHG gases are a small group, and nuclear war where the number of warheads is relatively limited, the number of ways that a global pandemic can start is almost unlimited.

Making things worse too is the fact that a global pandemic that reached the infinite threshold would most certainly be very different from almost all earlier pandemics, and maybe something totally new that has never happened before. Understanding more than the most basic sequence therefore becomes a challenge.

When it comes to data availability for pandemics the situation is different compared with nuclear war or climate change, where the impact depends on something that can be removed (nuclear weapons and GHG gases). It is not possible to get rid of mutating viruses and other organisms, so the data needed is of another kind and magnitude. There will always be new diseases emerging, because there is constant evolution, resulting in microbes looking for ecological niches.

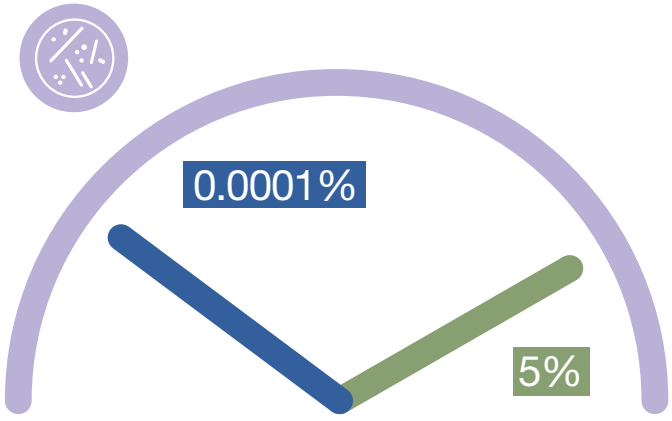
With many of the spillover effects occurring in remote areas, even basic data is still very rudimentary. Scientists who collect data relevant for pandemics are often working with very small resources, and there is no systematic way of collecting data on a global scale, although interesting initiatives are under way.[607] While an early warning system would be comparatively inexpensive, there are still no resources available.

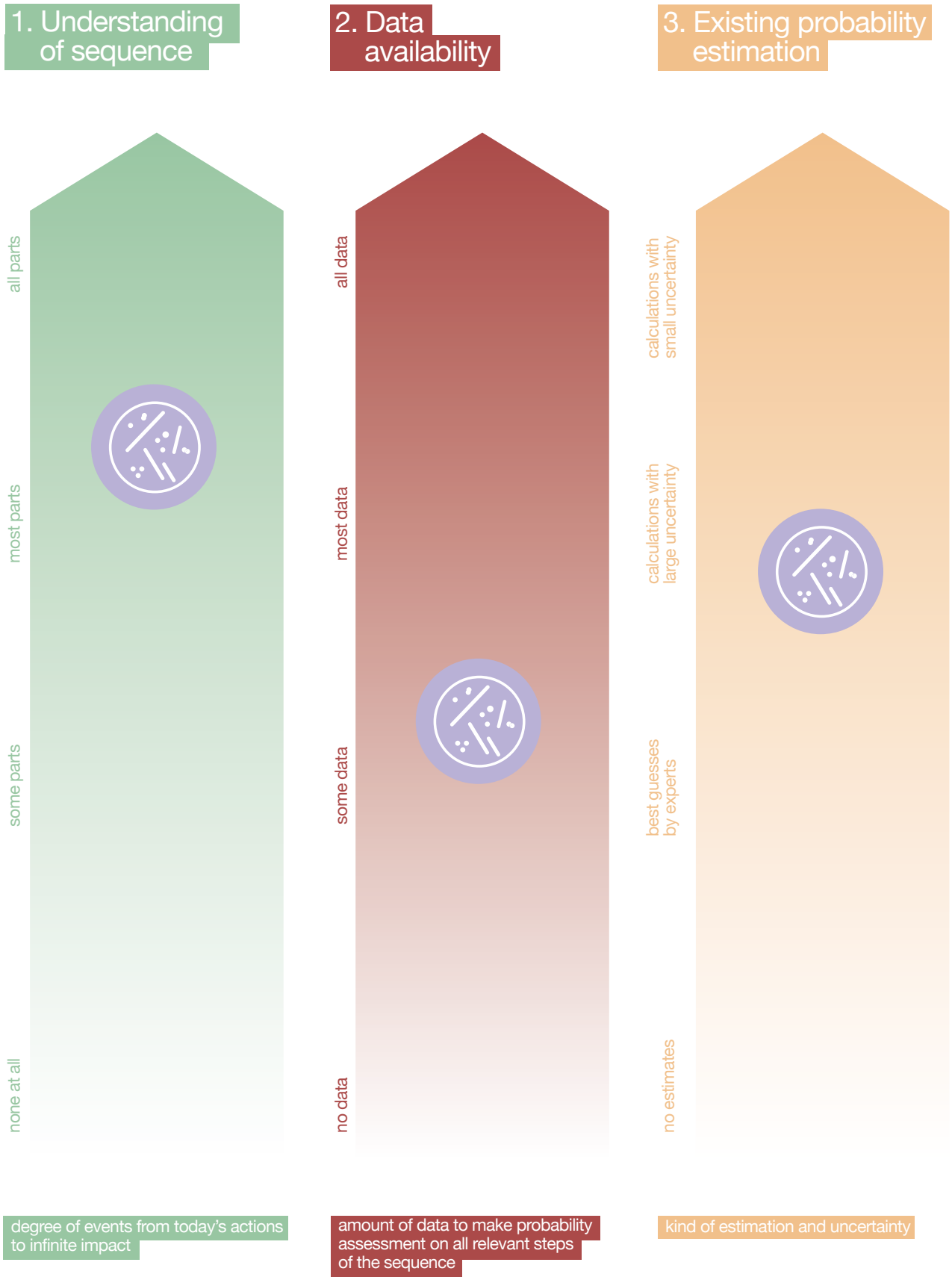
Most of the probability estimates made for pandemics are for their more benign versions. For the possible pandemic that could kill two billion or more there are very few estimates.

Based on available assessments[608] the best current estimate of a global pandemic in the next 100 years is:

5% for infinite threshold,
0.0001% for infinite impact

The reason for the big difference between threshold and impact is mainly that a pandemic will not directly affect infrastructure or the rest of the ecosystem in the way that extreme climate change or nuclear war would. This means that resilience will be relatively better after the infinite threshold is crossed.

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Ecological Catastrophe [609]

This is one of the more complex risks as it can be seen more as a heading than a description of a specific challenge with a well-defined sequence. In other words it is not one sequence, but very many still unknown sequences. The concept of ecological collapse usually refers to a situation where some part of the ecological web becomes so weak that it collapses.

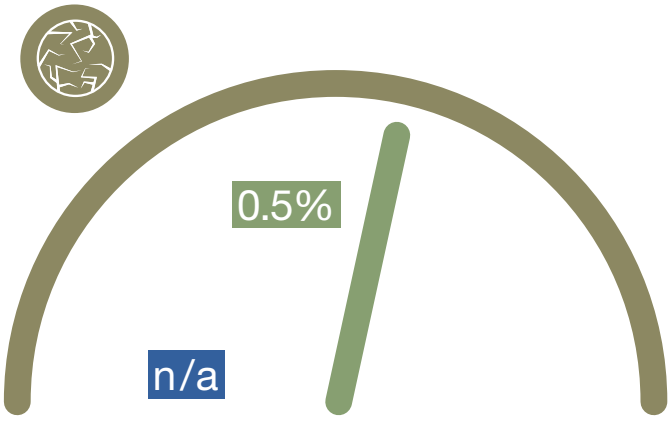
There are many studies about the stability and possible collapse of different ecosystems, but there are few that look into the possibility for a full ecological collapse that would result in at least two billion people suffering.

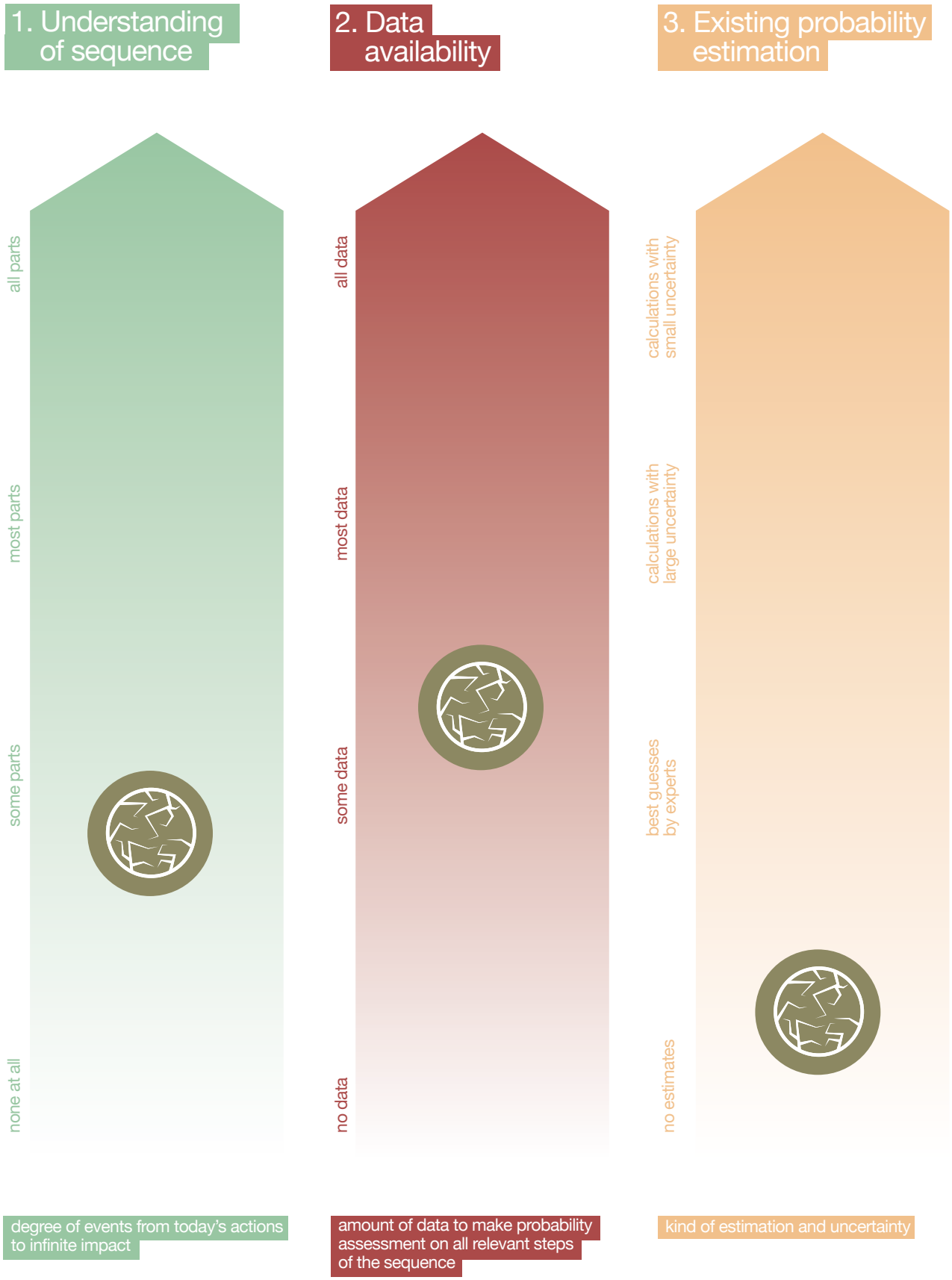
Data availability is good in many areas, but the challenge is that without an understanding of the system dynamics, and because of its complexity, there are inherent limits to how exact the knowledge is that can be achieved.[610]

Regarding probability estimates, it is only ecological collapse and global system collapse of the current man-made global challenges that have no estimates for infinite impact.

Based on available assessments[611] the best current estimate of an ecological catastrophe in the next 100 years is:

0.5% for infinite threshold,
Not available for infinite impact

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Global System Collapse

Since the financial crisis the possibility of a global collapse of the current political, economic and financial system has been discussed intensively. A rapidly evolving and increasingly interconnected system, it is subject to unexpected, system-wide failures because of the structure of the network – it faces a systemic risk.

Possible sequences for a global system collapse resulting in infinite impacts are very hard to establish, for three reasons. First, it is a very complicated system, with many dynamic interactions, as there are many people who together with machines react to each other. The current global system shows a lot of complex dynamic phenomena, such as business cycles, financial crises, irregular growth, and bullwhip effect.[612] Many nonlinear dynamic models of economics and finance present various complex dynamic behaviours such as chaos, fractals, and bifurcation.

Second, it is a rec ent system that has been so interconnected for only a few years, as it depends on an infrastructure that did not exist before the internet, so there is little experience of how it works.

Third, the system is rapidly changing and becoming even more complex as more connections are added and its speed increases. Better understanding of complex systems with multiple attractors and bifurcation behaviour will help improve the possibility of understanding the possible sequences.[613]

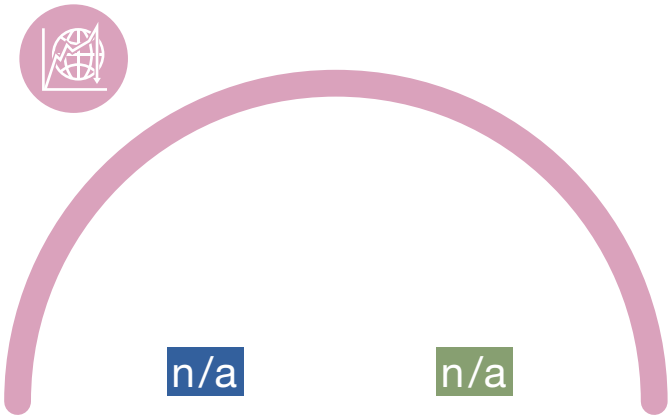
An additional challenge for the understanding of sequences that can result in impacts beyond the infinite threshold is that almost all research being done in the area of global system collapse focuses on its economic or geopolitical implications, not on a full system collapse and not on human suffering.

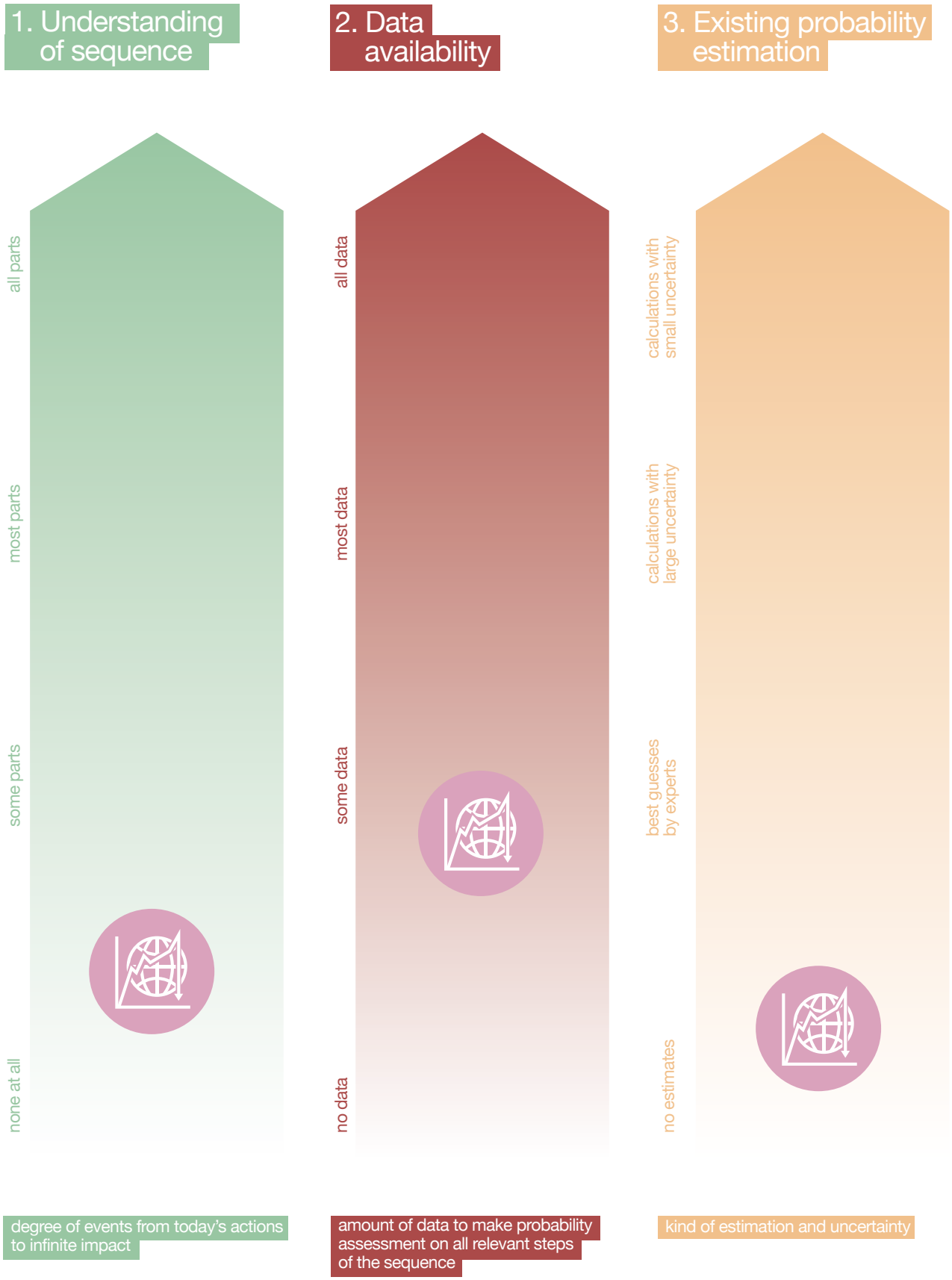
The data availability of global system collapse is something of a paradox. On the one hand the system is almost nothing but information, but at the same time data about how the system itself operates, what algorithms are used, and so on,, are not well known.

No estimate of the probability of a global system collapse that would result in an impact beyond the infinite threshold has been identified during the project.

Based on available assessments the best current estimate of a global system collapse in the next 100 years is:

Not available for infinite threshold,
Not available for infinite impact

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Major Asteroid Impact

The understanding of sequence when it comes to asteroid impacts is relatively straightforward and our planet is constantly experiencing asteroids, so assumptions can be tested. This, combined with the fact that there has been a number of major impacts in the Earth's history, makes the sequence reasonably well known.[614]

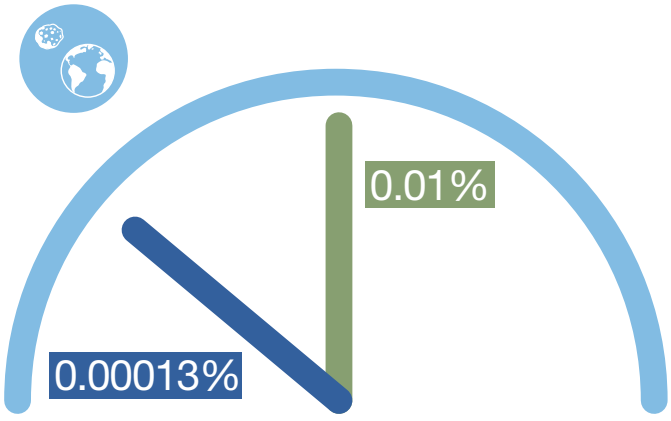
The data availability is still far from perfect, but it is rapidly improving. Currently NASA has a table with potential future Earth impact events that the JPL Sentry System has detected, based on currently available observations.[615]

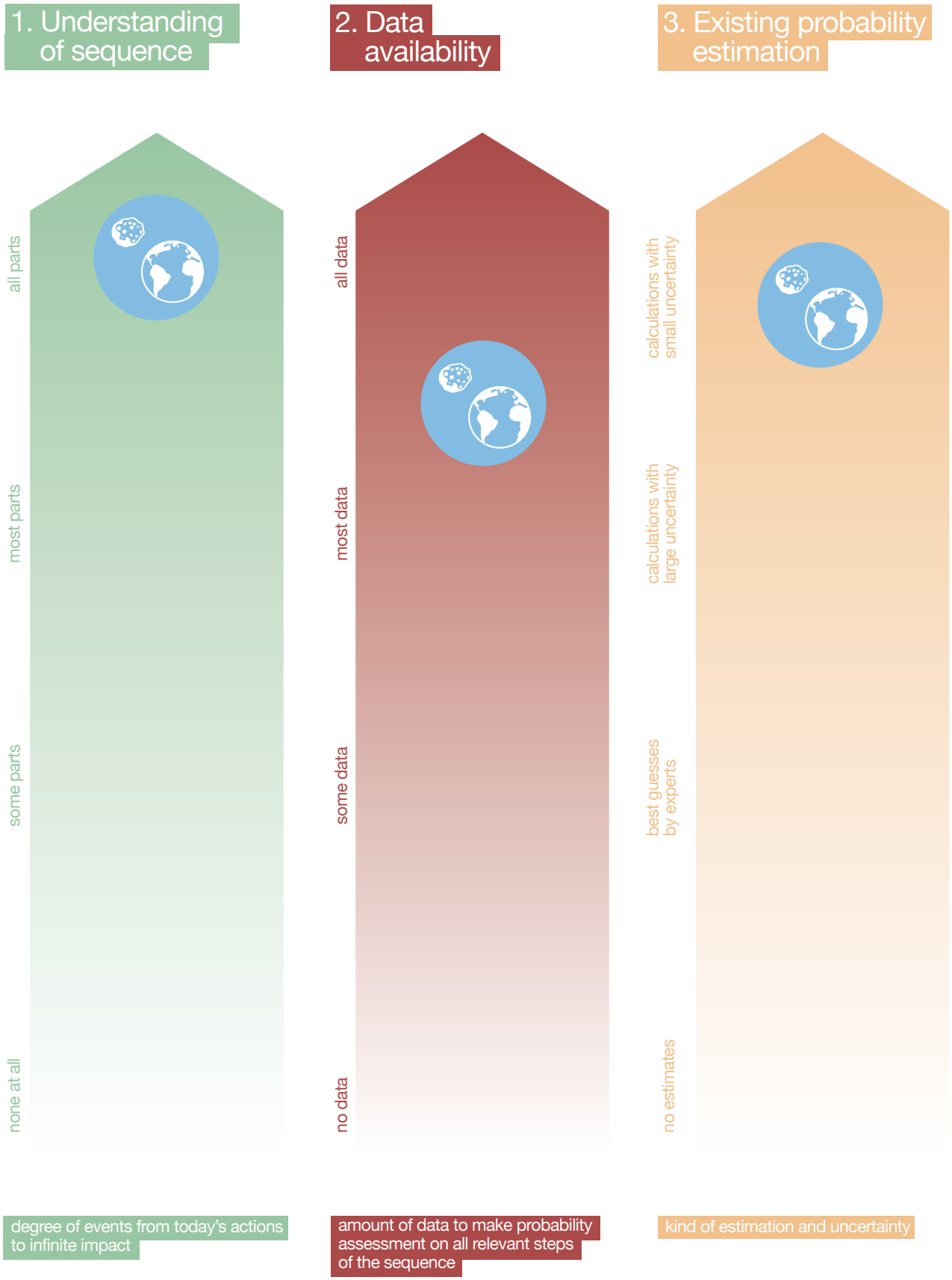
Other initiatives, like the the Sentinel Mission by the B612 foundation, are under way that will further improve availability.

Compared with most other global challenges there are many probability estimates with transparent methodology, and the degree of uncertainty is relatively low compared with other challenges. NASA even has an overview of the probability of individual objects hitting Earth.[617] For the most severe impacts the size of the asteroid will make it visible years in advance and this will only improve as our capacity to scan the space around us increases.

Based on available assessments[618] the best current estimate of a major asteroid impact in the next 100 years is:

0.01% for infinite threshold,
0.00013% for infinite impact

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Super-volcano

The super-volcano risk has many similarities with a major asteroid risk. Both have happened a number of times through our planet's history, and both have had major consequences.

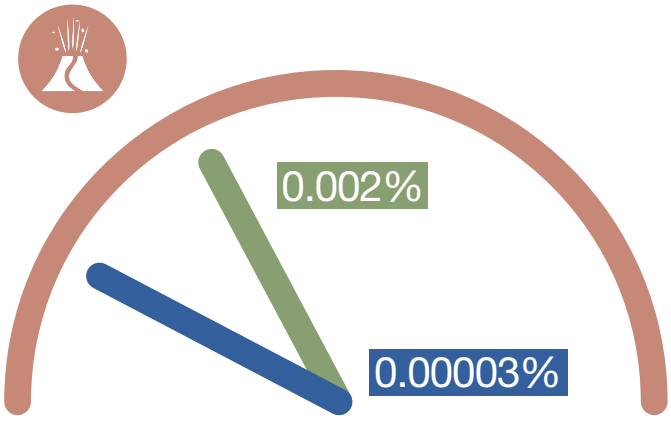
The understanding of the sequence is however a lot lower than for asteroids, as the mechanisms behind volcano eruptions are not very well known. The possibility of foreseeing when a super-volcano will erupt and how big the impact will be is therefore low. Compared with a major asteroid, there will therefore be much less time to prepare.

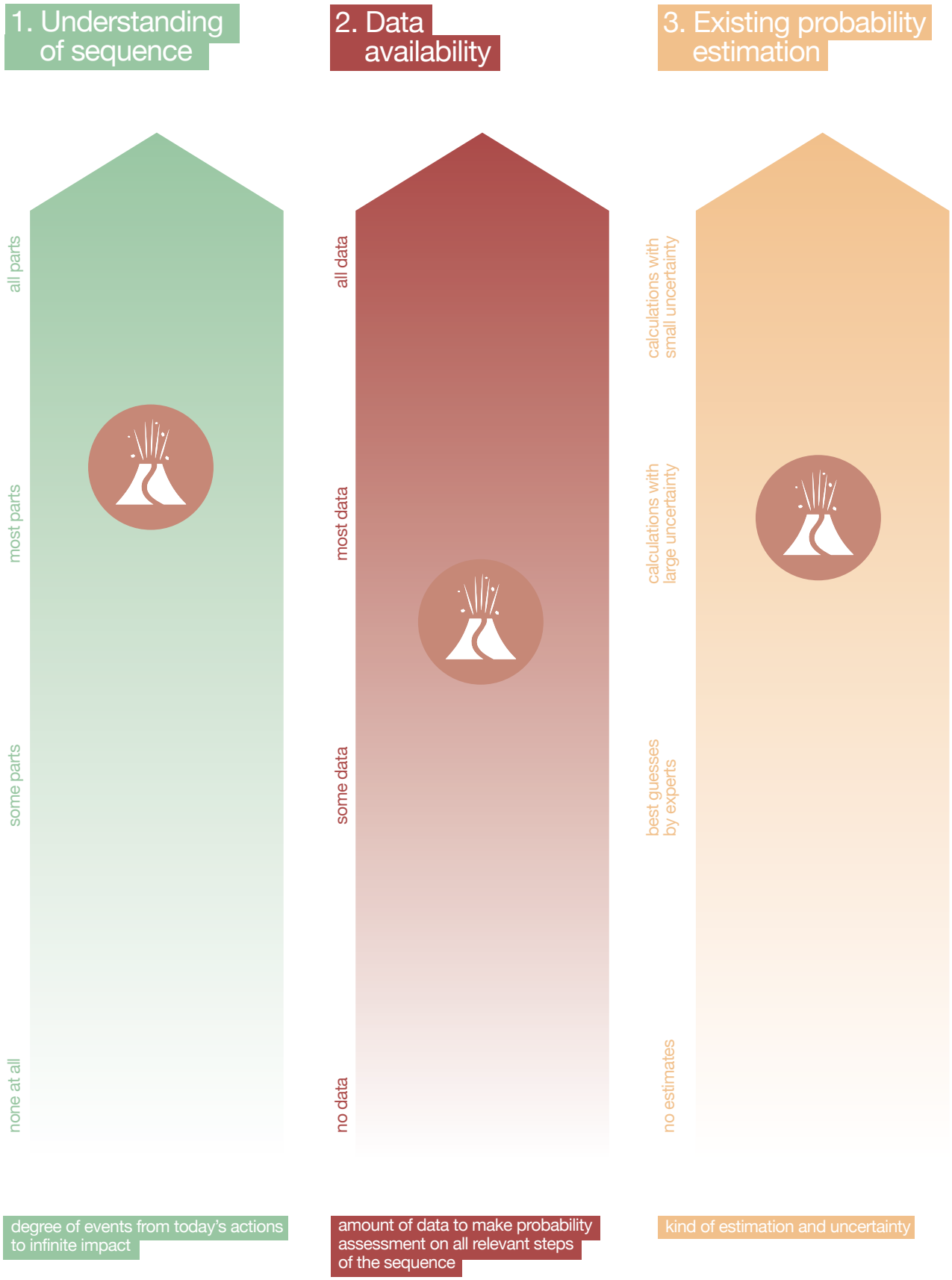
There is data available for different impacts, and knowledge of where super- volcanoes might erupt is increasing, but due to the lack of understanding when it comes to the sequence the probability estimations are still very rudimentary.

A number of estimates exist where the probability is assessed, but they are quite rudimentary, based on the historic frequency of earlier super-volcano eruptions. As these are so infrequent, the uncertainty becomes very significant.

Based on available assessments[619] the best current estimate of a super-volcano in the next 100 years is:

0.002% for infinite threshold,
0.00003% for infinite impact

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Synthetic Biology

Many experts see synthetic biology as the most serious future risk. The ability already exists to develop very deadly viruses, and as knowledge and technology develop further more deadly pandemics can be developed by an increasing number of people.

The basic sequence is relatively well-known, given that it would be a more deadly version of a current virus, but there is also the possibility that a new virus (or other organism) may be found where the sequence will be unknown and therefore also much more dangerous.

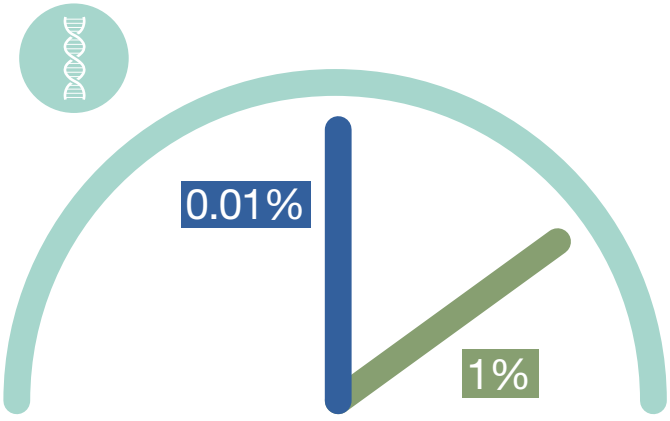
One of the challenges to understanding the sequence is that the spreading of synthetic biology will come either from a wilful act (e.g. terrorism) or an accident (e.g. unintentional release from a laboratory). This also makes data hard to get. There are some numbers for accidents in labs, but they are available in only a few countries and there are probably many more than those reported.[620] With terrorist acts there are probability estimates that can be used as a basis for the use of synthetic biology as well.[621]

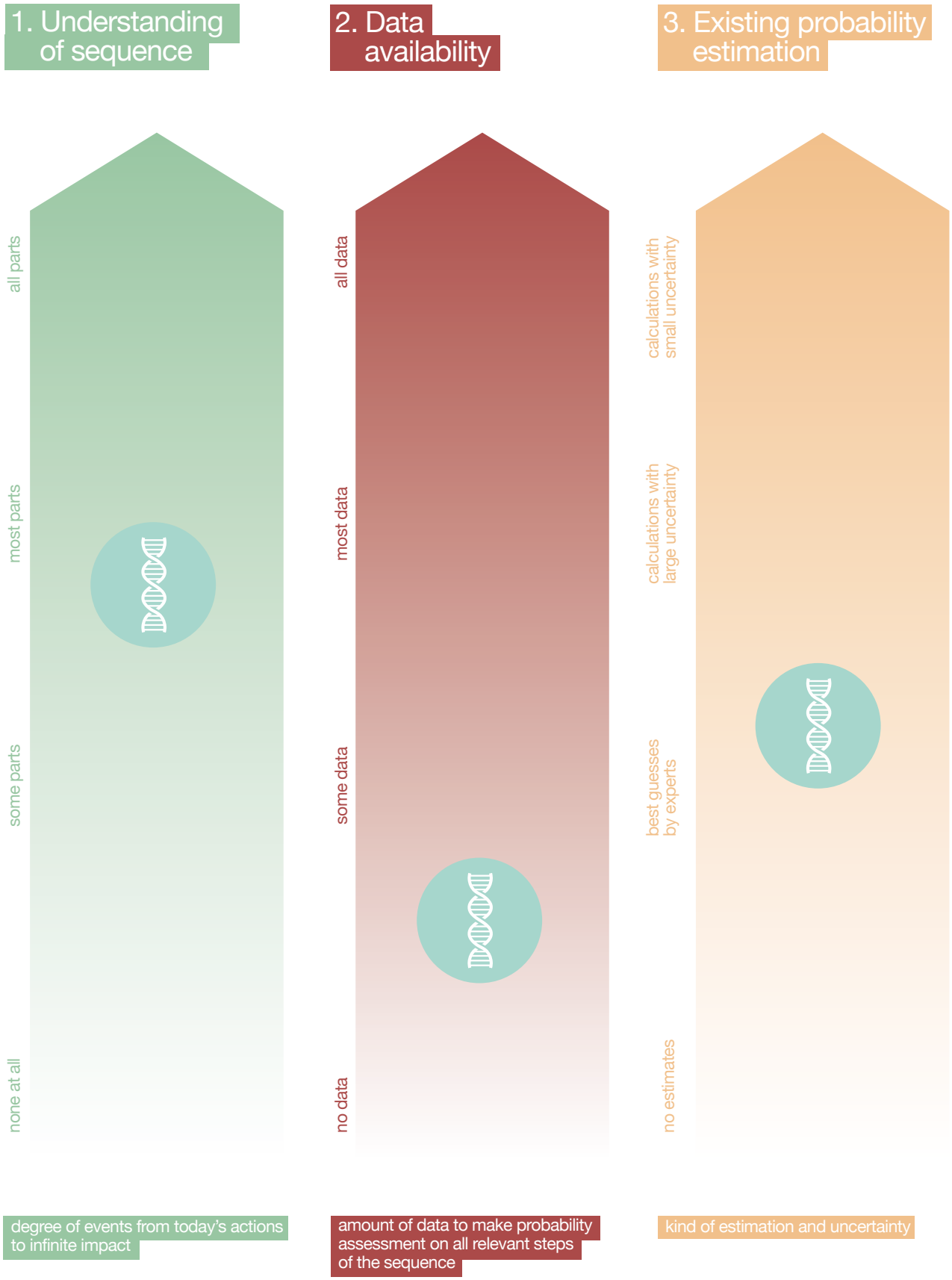
There are some existing estimates for synthetic biology, but these are based on possible use in war, where calculations depend on some specific differences from existing pathogens that are assumed to be necessary for a pandemic with an infinite impact.

Based on available assessments[622] the best current estimate of an impact from synthetic biology in the next 100 years is:

1% for infinite threshold,
0.01% for infinite impact

The probability numbers for synthetic biology are very high and can hopefully be reduced once better monitoring is in place, together with increased global collaboration.

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Nanotechnology

Nanotechnology is best described as a general capacity, rather than a specific tool. In relation to infinite impacts this is a challenge, as there are many ways that nanotechnology can be used that could result in infinite impacts, but also many others where it can help reduce infinite impacts.

Different possible sequences from today's situation to precise atomic manufacturing are well documented and the probability that none of the possible paths would deliver results is very small. What specific sequence and with what results is however very uncertain.

Compared with many other global challenges nanotechnology could result in many different risks - and opportunities, from an accelerated ability to manufacture (new) weapons[623] to the creation of new materials and substances. These are certainly orders of magnitude more likely, far likelier than any probability of the "grey goo" that has resulted in significant misunderstanding.

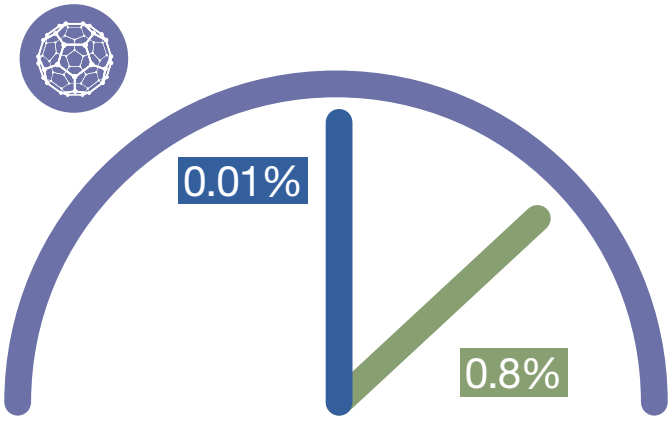
The data availability is difficult to estimate as there are very different kinds of data, and also an obvious lack of data, as nanotechnology is in its very early days.

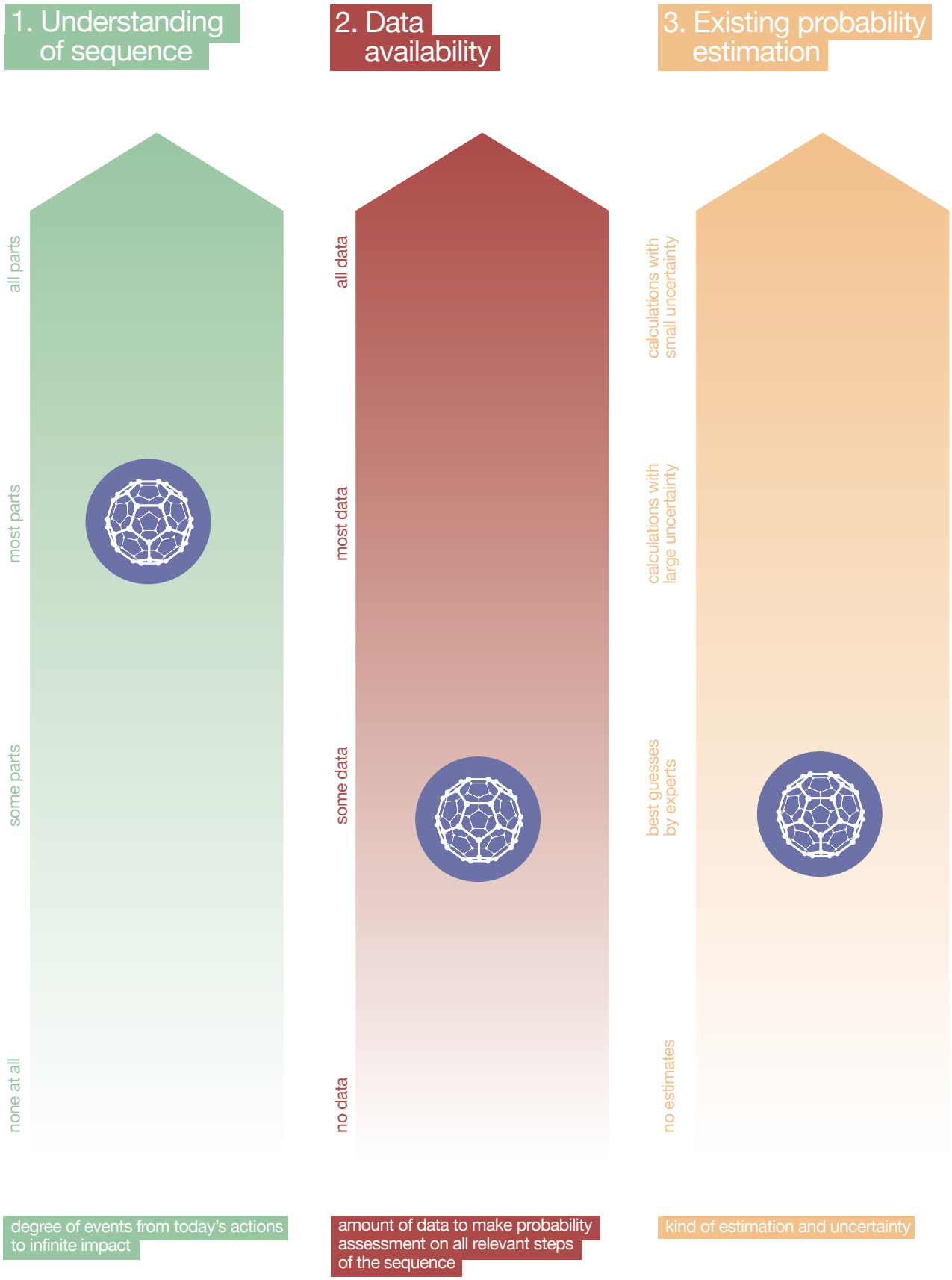
There are some estimates from experts, but the uncertainty is significant. A relative probability estimate is a possible first step, comparing nanotechnology solutions with existing systems where the probability is better known.

Admiral David E. Jeremiah, for example, said at the 1995 Foresight Conference on Molecular Technology: "Military applications of molecular manufacturing have even greater potential than nuclear weapons to radically change the balance of power." [624] A systems-forecasting approach could probably provide better estimates and help develop complementary measures that would support the positive parts of nanotechnology while reducing the negative.

Based on available assessments[625] the best current estimate of an impact from nanotechnology in the next 100 years is:

0.8% for infinite threshold,
0.01% for infinite impact




1. Understanding of sequence
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degree of events from today's actions to infinite impact
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amount of data to make probability assessment on all relevant steps of the sequence
3. Existing probability estimation
calculations with small uncertainty
calculations with large uncertainty
best guesses by experts
no estimates
kind of estimation and uncertainty

Artificial Intelligence

Artificial Intelligence is the global risk where least is known. Not even those who see the possibility of developing an AI claim to be able to describe what a working AI is in detail, let alone provide a description of the sequence from where we are today to an AI that could result in infinite impact.

The assumptions for an AI are based on the current rapid technological development, but as it is not even possible to simulate a simple version of AI it is hard to get any data.

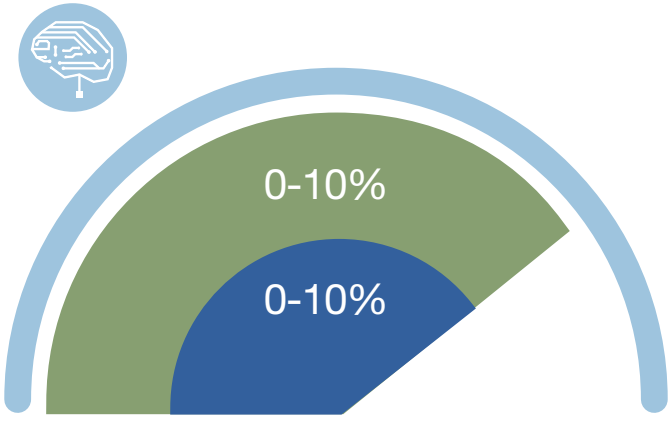
What is possible is to define a number of general factors determining risk. These include Capability and Compatible goals.[626] For global challenges in rapidly evolving areas where incremental development might not happen and little is known about the sequence, the only way to reduce risks with possible infinite impacts might be to ensure focus on these general factors.

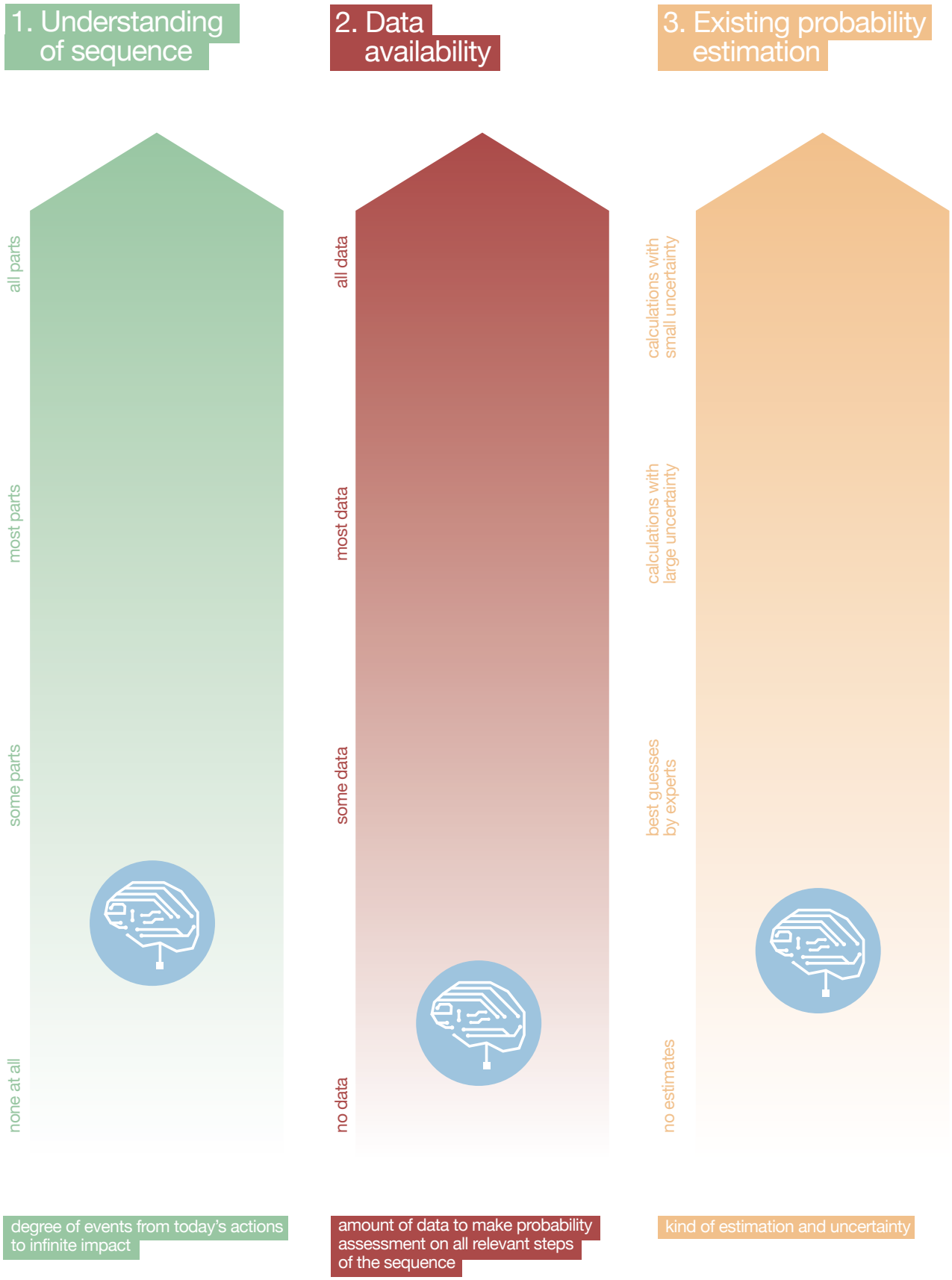
The only estimates of probabilities that exist so far have been made by a small group with a significant proportion of people with a passion for AI. Compared with many other challenges the possibility of an AI capable of infinite impact can almost be described as all or nothing. This is also why the estimates are the same for the infinite threshold and the infinite impact.

Based on available assessments[627] the best current estimate of an impact from AI in the next 100 years is:

0-10% for infinite threshold,
0-10% for infinite impact

The reason for 0-10% on both impact levels is that most experts assume that the kind of AI capable of impacts beyond the infinite threshold is likely to be one that also can result in an infinite impact. If we succeed it will move beyond control very rapidly. Due to the significant impact it would have if it worked, there is no difference between the two impact levels.

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no estimates
kind of estimation and uncertainty

Unknown Consequences

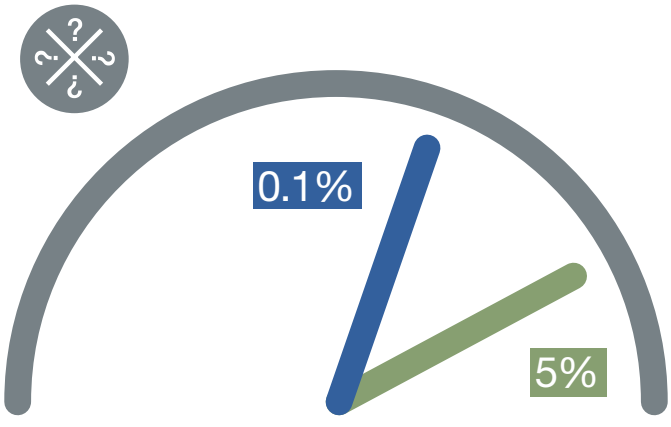
Uncertain risks must be included in any project addressing low-probability high-impact events. The way to approach uncertain risks is, by definition, uncertain.

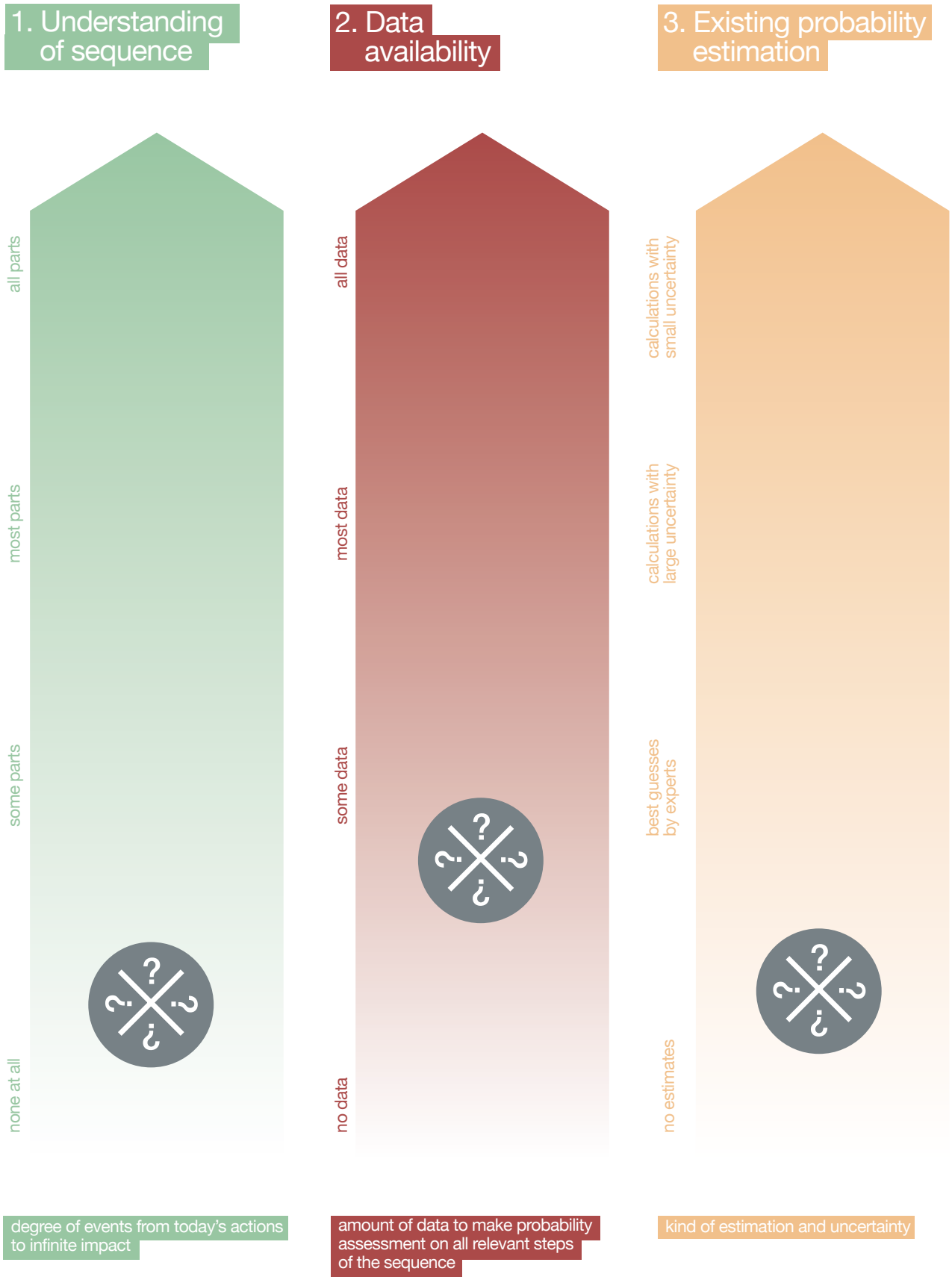
The sequence can only be assessed on the basis of experience of unexpected events, so actual data does not exist.

But we know from history that these kinds of events happen over and over again. With rapid technological development and increased tensions over coming decades, the magnitude of the impacts can be assumed to increase. The probability estimates exist only as best guesses by experts, and while it is possible to make the assessments more formal it is currently the best existing estimates that at least provide a preliminary order of magnitude for these risks.

Based on available assessments[628] the best current estimate of an uncertain risk in the next 100 years is:

5% for infinite threshold,
0.1% for infinite impact

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Future Bad Global Governance

As there is no global government, global governance today typically involves a range of actors including states, regional and international organisations. A single organisation may nominally be given the lead role on an issue.[629]

Future bad global governance is an important challenge, although it is totally different from the other challenges. We should remember that at present about two billion people live in poverty, and the risks from global challenges are increasing. No governance system is perfect, but it is possible to improve significantly on the current system without increasing the risks.

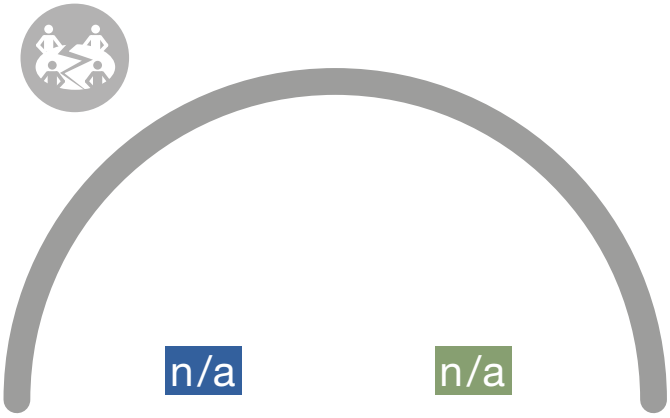
The probability of a bad global governance system will increase the longer it takes to implement solutions to address global challenges. When the world experiences significant negative impacts, the time for reflection will be shorter and polarisation is likely to increase.

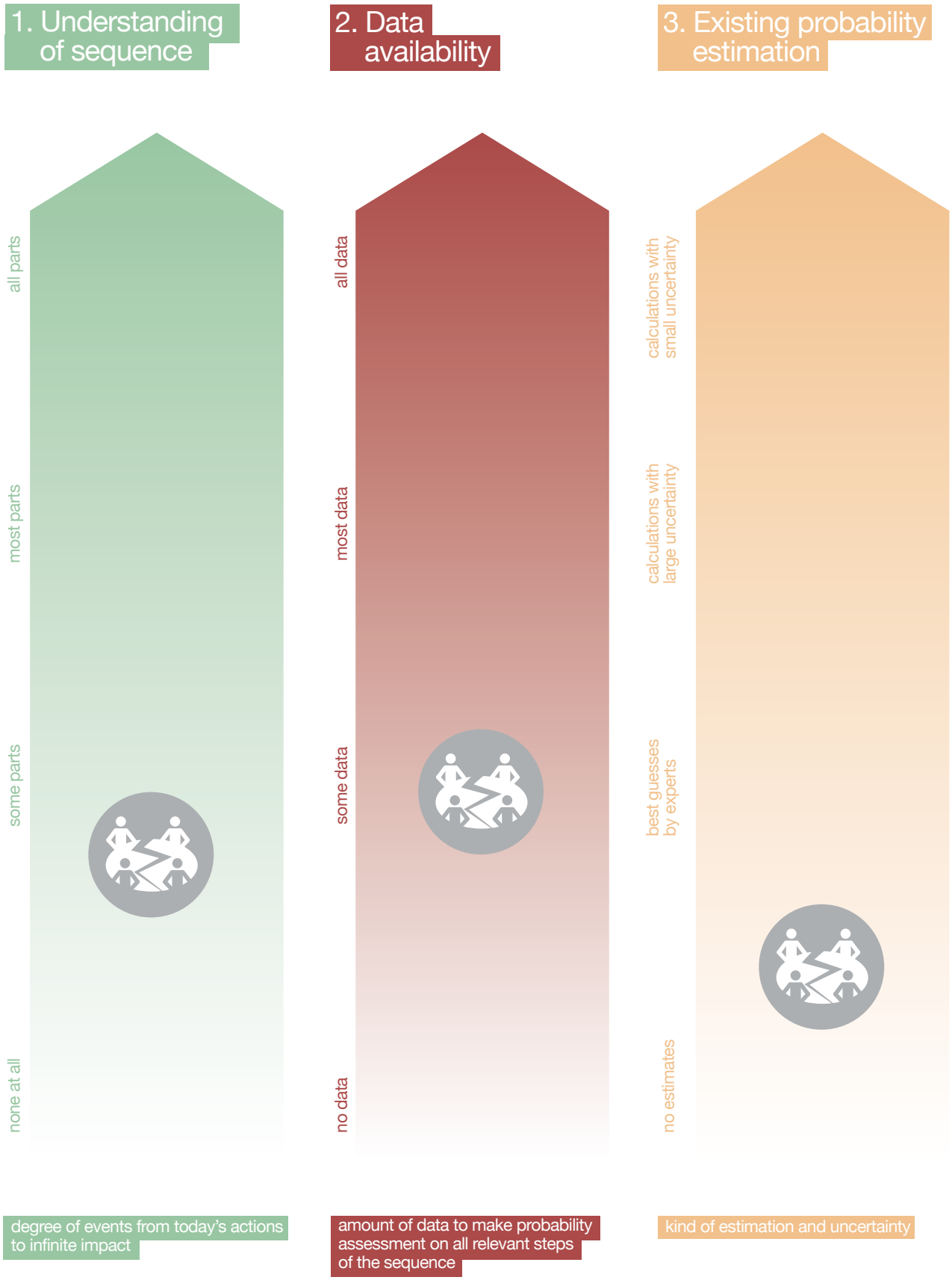
To establish a failed governance system on a global level will require something extraordinary, as nations tend to protect their national sovereignty at almost any cost.

What can help in understanding possible sequences is an increasing amount of data on how complex organisations work and the psychology of organisations that can create destructive patterns.[630]

Based on available assessments the best current estimate of a future bad global governance with potentially infinite impacts in the next 100 years is:

Not available for infinite threshold,
Not available for infinite impact

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6. Underlying trends of key importance

Those who do not remember the past are condemned to repeat it.

George Santayana

To address the global challenges means recognising several underlying trends. These will influence the challenges by affecting society as a whole as well as more directly affecting the challenges. Currently most risk assessments and other studies related to global challenges neglect the fact that these trends can have very different outcomes.

The most common mistake is that the most likely development of these underlying trends is taken for granted as the only possible outcome. Most of the trends have probability distributions where low-probability/high-impact possibilities are often ignored. In this chapter some of the most important trends, where the possible outcomes can differ significantly, are described through a global risk perspective .

For each of the trends the simple rule based on a risk perspective is: "Aim for the best, but be prepared for the worst".

6.1 Poverty

Global poverty has fallen dramatically over the last two centuries, and the fall has intensified in recent decades, raising hopes that poverty, defined by the World Bank as an income below US$1.25 per day, may be eliminated within the next 50 years. The Economist even had a cover, in June 2013, with the title "Towards the end of poverty".[631] The World Bank has set an interim target of reducing global extreme poverty to 9% of the world's population by 2020, which, if achieved, would mark the first time the rate has fallen to single digits.[632] The milestone is based on a World Bank economic analysis of global poverty trends aimed at the goal of ending extreme poverty by 2030.

Reaching 9% in 2020 would mean an estimated 690 m people would still be living in extreme poverty by then, 510 m fewer in poverty than a decade earlier. That would be the equivalent of half the population of Africa, or more than double the population of Indonesia.[633]

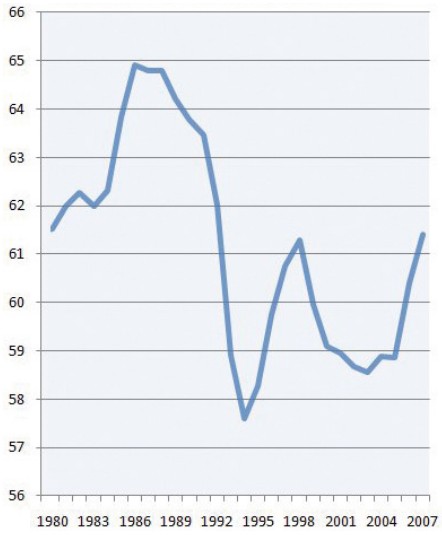
There are reasons to celebrate this development as more people than ever live a life where they do not have to constantly worry about their most basic needs. But there are two things worth remembering:

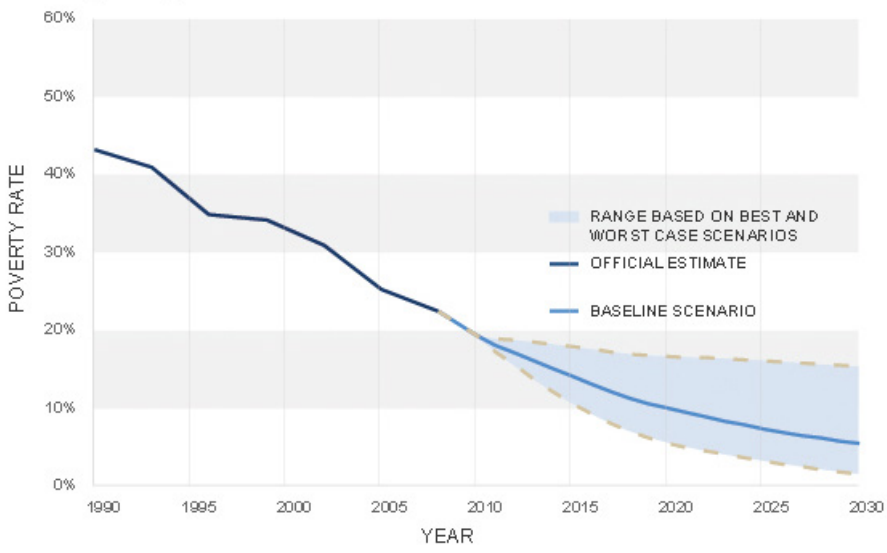
1. Poverty could increase again.
2. Defining poverty is difficult.

Today very few people assume that poverty could increase again. But everything from economic crisis and pandemics to climate change and wars could change that. The situation after the fall of the Soviet Union resulted in increased poverty.[634]

Even conservative estimates show that the percentage of people in poverty by 2030 could range from almost zero to nearly 20%.[636]

Figure 25: Russian Male Life Expectancy[635]
Figure 26: Prospects for Ending Extreme Poverty by 2030.[637]





Even more complicated is the definition of poverty. The level of $1.25 is a very rough indicator and does not say very much about the situation of the people living life at that level. How desperate are they (important for war/terrorism)? What risks do they feel they must take (important for climate change and ecological collapse as people will engage in illegal deforestation)? Poverty is also important in pandemics, as reduced income can result in increased migration and also increased hunting of wild animals.

Understanding the relationship between poverty and global challenges requires us to develop strategies that help ensure poverty reduction. Planning means it is important to assume different levels of poverty reduction - for example: For successful poverty reduction, low-carbon solutions are crucial, as it is rich people who are the main emitters on the planet because of their unsustainable lifestyles. If poverty reduction is unsuccessful, structures to address a higher likelihood of outbreaks that can turn into pandemics are required as poor people tend to live in societies where they are more likely to get infected and where often even basic health service is lacking .

The conclusion is that climate strategies should prepare for successful poverty reduction by setting targets and developing solutions that work in a world with low poverty, and should not assume high levels of poverty. At the same time our strategies for pandemics must assume that poverty reduction could fail and develop solutions accordingly.

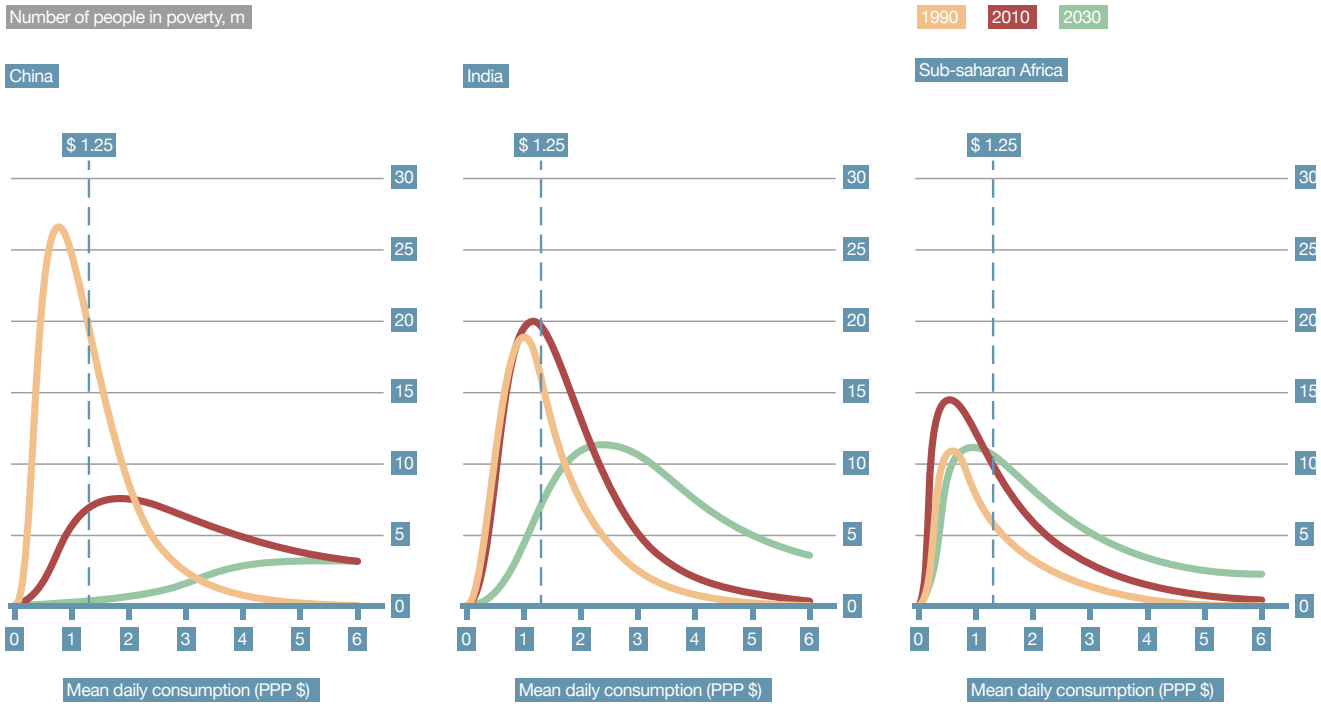


Figure 27: Different kinds of poverty - Number of people in poverty[638]

6.2 Population growth

Population growth is a trend that has been discussed intensively from a sustainability and risk perspective since Malthus did his famous projection.[639]

A "natural population increase" occurs when the birth rate is higher than the death rate. While a country's population growth rate depends on this natural increase and on migration, global population growth is determined exclusively by natural increase.[640]

Around the world, death rates gradually decreased in the late 19th and the 20th centuries, with those in developing countries plummeting after World War II thanks to the spread of modern medicine which allowed control of infectious diseases.[641]

According to the 2012 Revision of the official United Nations population estimates and projections, the world population of 7.2 billion in mid-2013 is projected to increase by almost one bn people within twelve years, reaching 8.1 bn in 2025, and to further increase to 9.6 bn in 2050 and 10.9 bn by 2100.[642]

These results are based on the medium-variant projection, which assumes a decline of fertility for countries where large families are still prevalent as well as a slight increase of fertility in several countries with fewer than two children per woman on average.[643]

The medium projection is still dramatic as it assumes another four bn people on the planet, more than a 50% increase in population, equal to the Earth's entire population in 1975, in just 86 years.[644]

The high-variant projection depicted in the figure below assumes an extra half a child per woman (on average) compared with the medium variant, implying a world population of 10.9 bn in 2050 and 16.6 bn in 2100.[645] That is equal to a 133% population increase in just 86 years .

The difference between projections for 2100, from 10.9 bn people in the medium scenario,to 16.6 bn in the high scenario, equals the world population in 1995. There is also a credible low scenario with 6.8 bn by 2100.[646] A strategic approach must be based on all possible outcomes. Planning as though the world population will be only 6.8 bn is not optimistic: it is unscientific and dangerous. Even to plan for a world with 10.9 bn is not strategic as this would ignore the significant probability that the world's population would be much larger . There should be a plan for a world with 16.6 bn people, combined with a long-term strategy to ensure a sustainable population level.

It is also important to ensure that more attention is paid to early warning systems that allow us to influence population development in a sustainable direction.

The fact that projections can change is clearly demonstrated by the difference between the current (2012) revision, and the 2010 Revision of World Population Prospects. The latter was published only two years earlier and projected world population reaching 9.3 bn in 2050 and 10.1 bn in 2100 (medium variant).[647] This is almost a 10% difference in the space of two years.

Current ways to provide the lifestyles enjoyed in countries like the UK and US today would require 3.5- 5 planets, while the global population is about 7 bn people.[648] Under the high-variant projection, more than 10 planets would be needed.

With other underlying trends technology breakthroughs and institutional changes can result in very rapid changes. Global population growth cannot change as rapidly. And as it is related to many factors, including other underlying trends such as income levels, education, access to health services and cultural values that are all assumed to be undergoing significant changes over coming decades, population growth over long time periods is even more difficult to estimate.

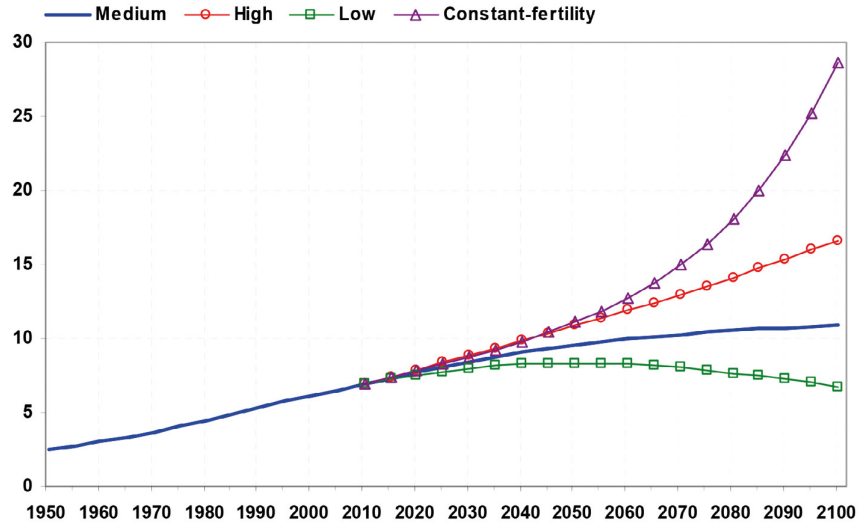


Figure 28: Population of the world, 1950-2100, according to different projections and variants
Source: http://esa.un.org/wpp/documentation/pdf/WPP2012_Volume-I_Comprehensive-Tables.pdf, p. xv

6.3 Technological development

Technological development since the industrial revolution has been faster than most experts expected. For material welfare this has been very positive; average longevity and health improvements in general have all shown dramatic positive development. During the second half of the 20th century global health improved more than in all previous human history. Average life expectancy at birth in low- and middle-income countries increased from 40 years in 1950 to 65 years in 1998.[649]

While weapons have become more deadly the death toll from wars has actually decreased over time.[650] How big a part technology has played by creating greater transparency, or increasing the fear of using weapons which have become too powerful (for example nuclear bombs), is disputed. But most experts agree that technology has played an important role.[651] This is not the same as saying that this development will continue.

Estimating the future development of technology is very difficult. On the one hand there is evidence that technology will continue to accelerate at the pace it has achieved so far. Researchers at MIT and the Santa Fe Institute have found that some widely used formulas for predicting how rapidly technology will advance — notably, Moore's and Wright's Laws — offer superior approximations of the pace of technological progress.[652] Experts like Ray Kurzweil, who was recently hired by Google, is one of those who think that most people do not understand the implications of exponential growth in the area of technology and the results it generates in price, capacity and overall transformation of society.[653]

On the other hand there are natural limits that could begin to constrain technological development in two ways. The technology itself may hit a barrier. For example, at some stage a processor may not continue to become smaller and faster, as the speed of light and quantum mechanics will limit its development.[654] There might be other ways to overcome such boundaries, but no exponential trend can last forever. Second, nature itself may set limits. We may choose to take more care of the planet, or limits to materials like rare earths may begin to slow technology.[655] But regardless of ultimate limits, many exponential trends are likely to continue over the coming decades and will present us with new opportunities as well as risks in the 21st century, as these trends converge in a society with 20th century institutions.

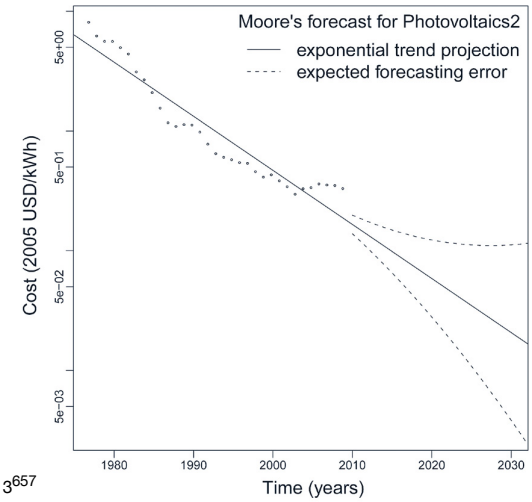


Figure 29: Moore's forecast for PV[656]

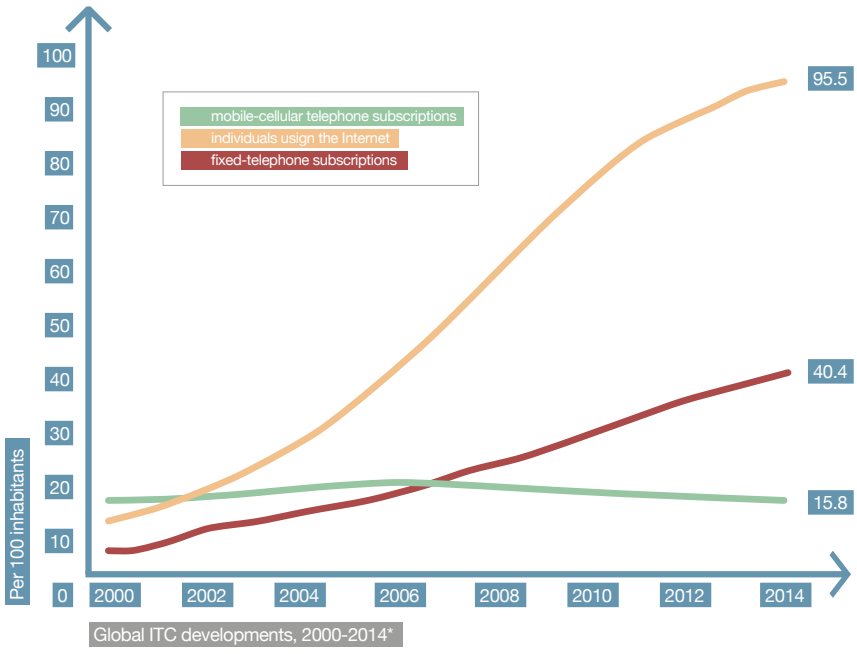


Figure 30: Global ICT development 2000-2013[657]

How technological development can be supported in order to increase opportunities and reduce risks will be increasingly important to discuss.

As technology in many areas is developing exponentially it is important to analyse its development very carefully. The potential for technology to help solve existing and future global challenges is almost limitless. And so unfortunately is its potential to accelerate existing risks and create new ones. Too many initiatives today focus on only one side of technology, either the positive or the negative. Acknowledging both sides is necessary in order to ensure a strategic response.

6.4 Demographic changes

The world's population is undergoing a massive demographic shift. Fertility rates have fallen and the number of children has stopped growing. It is a historic shift.

Those who are 80 or more now make up only slightly more than 1% of the total human population. This proportion is projected to increase almost fourfold over the next 50 years, to reach 4.1% in 2050. Currently, only one country, Sweden, has more than 5% in this age group. By 2050 the over-80s are projected to number almost 379 mn people globally, about 5.5 times as many as in 2000 (69 mn). In 1950, the over-80s numbered under 14 mn.

Although the proportion of people who live beyond 100 is still very small, their number is growing rapidly.

In 2000 there were an estimated 180,000 centenarians globally. By 2050 they are projected to number 3.2 mn, an increase of about eighteen times.[659]

Within the more developed regions, Japan, in particular, will experience a remarkable increase in the number of centenarians over the next half century, from fewer than 13,000 in 2000 to almost 1 mn in 2050. By then Japan is expected to have by far the world's largest number and proportion of centenarians, nearly 1% of its population.[660]

The stagnating and ageing population in many OECD countries and China will put pressure on current systems, which were not designed to deal with a situation of ageing and often shrinking populations in many parts of the world, while the populations in other parts of the world are rapidly growing.

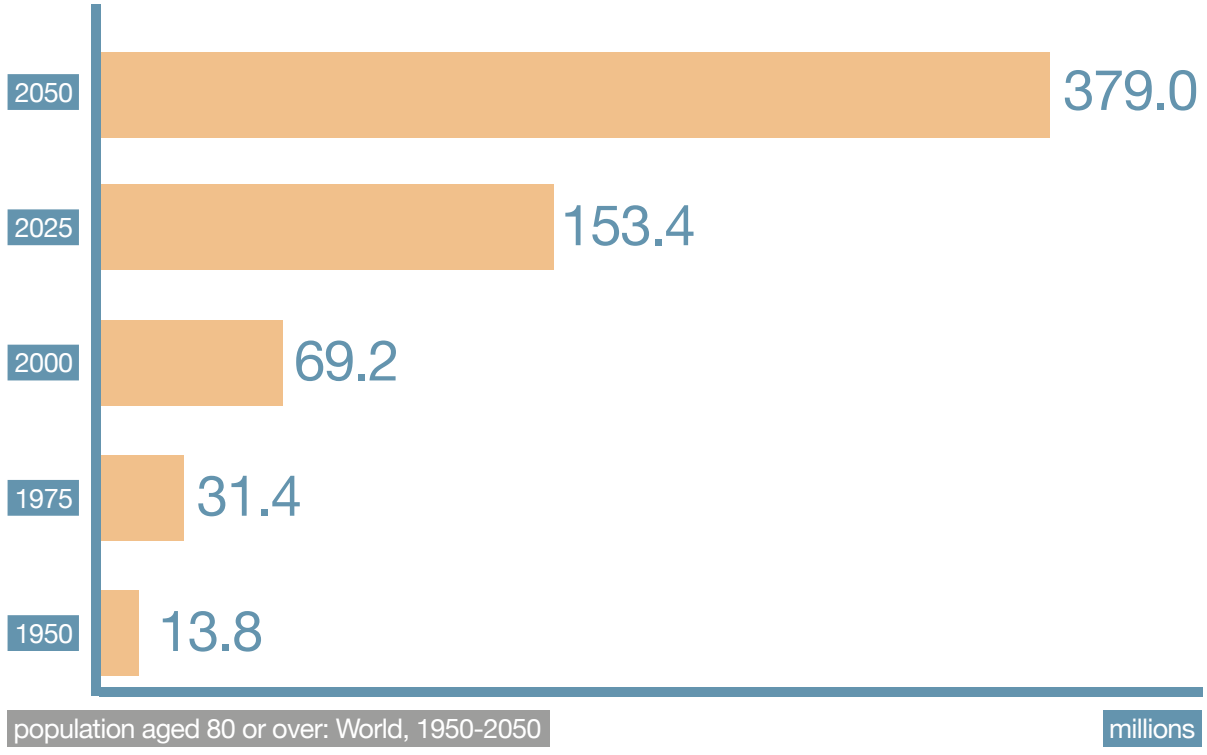


Figure 24: Population aged 80 or over[661]

7. Possible ways forward

Our very survival depends on our ability to stay awake, to adjust to new ideas, to remain vigilant and to face the challenge of change.

Martin Luther King Jr.

To better address global challenges with a possible infinite impact both immediate action and long-term work are needed. Below are ten areas that could help mitigate immediate threats while also contributing to a future global governance system capable of addressing global challenges with infinite impacts. For all these areas more research is needed.

1. Global challenges leadership networks

2. Better quality risk assessment for global challenges

3. Development of early warning systems

4. Encouraging visualisation of complex systems

5. Highlighting early movers

6. Including the whole probability distribution

7. Increasing the focus on the probability of extreme events

8. Encouraging appropriate language to describe extreme risks

9. Establishing a Global Risk and Opportunity Indicator to guide governance

10. Explore the possibility of establishing a Global Risk Organisation (GRO)

1. Global challenges leadership networks

The long-term goal needs to be the establishment of a transparent and democratic global governance system that can address global challenges with infinite impacts. To support this leadership networks can be established involving interested governments, major companies, NGOs, researchers and other relevant stakeholders. These networks could develop strategies to address multiple challenges with potential infinite impacts, and could work on a roadmap for a future global governance system that can address existing and new global challenges.

The networks should be as transparent and inclusive as possible, especially as global collaboration is needed. The use of new collaboration tools and principles, such as wiki-processes and creative commons, should be encouraged.

Four groups are of particular importance: experts in finance, experts in security policy, lawyers with knowledge of global risks and international law, and finally a group consisting of clusters of stakeholders with solutions that can reduce the risks. Leadership networks that include participants from all four groups are of particular interest.

2. Better quality risk assessment for global challenges

There is currently no global coordination when it comes to risk assessments of global challenges. Different experts use different methodologies, data and ways to present their results, making it very difficult to compare the risk assessments that exist. By establishing a process that coordinates and encourages risk assessments of global challenges, methodology development could be accelerated and improved, as the possibility of learning from different areas would increase. Such a process could also encourage increased investments in methodology development based on the latest innovations, such as systems-forecasting approaches.

Institutions and universities engaged in developing new methodologies to assess global risks have a particular responsibility for developing and refining risk assessments for global challenges.

3. Development of early warning systems

The rapid technological development has many benefits, but it also challenges as risks can rapidly become very serious and reach infinite thresholds. To develop early warning systems that can gather and process data transparently is therefore of the utmost importance. Technological progress, from smart phones and sensors to significant processing power and networks, allows for totally new ways of establishing early warning systems based on so-called "big data".[662] These opportunities include both new ways of collecting large amounts of high-quality data, and new ways to analyse them.

Early warning systems should be built to ensure that data is collected and analysed in ways that can be useful for multiple global challenges. The warnings should not only include changes in the physical world, but also indicate when decisions, investments and legal changes can be assumed to increase or decrease global risks. Such a system would allow more time to develop strategies to mitigate risks and turn global challenges into opportunities for innovation and collaboration.

The warning system would require significant research into infinity thresholds. Both traditional as well as more recent methodologies based on understanding of complex systems should be encouraged.

4. Encouraging visualisation of complex systems

The global challenges depend on a very complex ecosystem and social system.

With a global economic and technological system, which both helps and creates risks that are increasingly interconnected and difficult to understand, there is a challenge to understand the challenges.

New visualisation tools could help make complex systems easier to understand and also help the communication of challenges and opportunities.[663]

Visualisation tools are needed both for decision makers to highlight the consequences of different strategies and for citizens to increase their basic understanding of infinite impacts.

5. Highlighting early movers

Governments, companies, organisations and networks working on global challenges should increase their efforts to reward leadership when they find it Major news outlets can also report when significant positive steps are taken to reduce global risks with potential infinite impacts.

In particular, leadership with a focus on multiple global challenges and the relationship between them should be highlighted, as very little is being done in this area.

6. Including the whole probability distribution

Governments, major companies, NGOs, researchers and other relevant stakeholders should address the whole probability distribution, including low-probability high-impact scenarios. This would ensure that serious risks are not disregarded or obscured.

Current lack of data and of scientific studies regarding low-probability high-impact outcomes in many areas should not be used as an excuse to ignore the probability distribution. This is especially important when many of the global challenges have a very long and fat “tail”.

Tables, graphs and key conclusions in reports related to global challenges should, when possible, include the whole probability distribution.[664]

7. Increasing the focus on the probability of extreme events

When the impact is infinite it is not enough only to reveal the whole probability distribution. It is important also to avoid confusing uncertain risk with low risk.

Infinite impacts render many of the traditional models for risk management almost meaningless. Monetary calculations are often useless, and discounting is not always advisable.

Stakeholders should include the most extreme impacts in all relevant work. If the probability of infinite impacts increases instead of decreasing, because of new scientific findings or lack of action, strategies should be prepared to allow more decisive action.

The use of methodologies and approaches from security policy and the financial sector that focus on extreme events could be used to develop strategies for rapid action beyond the incremental approaches that dominate today.

8. Encouraging appropriate language to describe extreme risks

Often words like “unlikely”, “negligible” and “insignificant” are used to describe a risk when the probability is considered low. What is low is however relative; a low probability in one area can be extremely high in another. If I attend one of ten lectures - 10% - people might say there is a low probability that I will be there. But if someone says that a new aircraft crashes once in every ten flights, most people will say that is an extremely high probability and will be likely to assume it is an early prototype that is nowhere close to commercial success.

A major problem is that probabilities that ought to be seen as very very high for risks with potential infinite impact are described in a way that makes them sound less urgent than they are - by the media, business, politicians and even by scientists.

One example is how probabilities are described by the Intergovernmental Panel on Climate Change.

The IPCC uses specific and defined language in its reports to describe different probabilities and thus ensure clarity, but taken out of context and without supporting definitions this language can be misleading.

For example, the term “very unlikely” is used by the IPCC to describe a probability of between 0-10%,[665] but out of context its use could easily be understood as a normative judgement suggesting that we do not need to engage with the risk.

The language of the IPCC can be compared with that used in the Swedish national risk assessment (SNRA).[666] The scale of impact is not defined for the IPCC, but for the Swedish assessment it is:

Very small: no deaths or serious injuries

Small: One dead and/or 1-9 seriously injured

Average: 2-9 dead and/or 10-49 seriously injured

Large: 10-49 dead and/or 50-100 seriously injured

Very large: >50 dead and/or >100 seriously injured

The use of terms that can be interpreted as having normative values to explain probability is problematic and in future all bodies, including the IPCC, should explore the possibility of using only numbers in external communications, at least in the summary for policy makers, to help everyone understand the reality of the situation.

Stakeholders should explore ways to use language that better communicates how serious extreme risks are in the case of climate change, and where possible compare this with other risk areas to help illustrate the situation.

IPCC Term	SNRA Term	Likelihood of the Outcome: IPCC	Likelihood of the Outcome: SNRA
Very certainly	Very high	99-100% probability	> 20% [more than once every 5 years]
Very likely		90-100% probability	
Likely		66-100% probability	
About as likely as not		33-66% probability	
Unlikely			
	High		20%-2% [Between once every 5 years and once every 50 years]
Very unlikely	Average	0-10% probability	2%-0.02% [Between once every 50 years and once every 500 years]
Exceptionally unlikely		0-1% probability	
	Low		0.02%-0.002% [Between once every 500 years and once every 5000 years]
	Very low		< 0.002% [Less than once every 5000 years]

Figure 31: Comparing the probability scale in the Swedish national risk assessment[667] and the Likelihood Scale used by the IPCC[668]

9. Establishing a Global Risk and Opportunity Indicator to guide governance

No mechanisms currently exist to provide updated and comprehensive global risk assessments for phenomena capable of threatening human civilisation.

With many unsustainable trends converging, it is crucial that leaders are able to act before it is too late and to assess how actions, such as political decisions or investments by companies, influence the probability of different impacts and outcomes.

Establishing a global risk indicator, with sub-indicators for different areas, as part of the UN system would help create a better understanding of extreme global risks individually and of their interconnection, and it should track both. An important feature would be its ability to illustrate who has responsibility for increasing and decreasing the risk; who will suffer its consequences, and who will benefit.

Stakeholders should explore the establishment of a global risk indicator that will help guide priorities and inform society about different risks, and about the relationship between them.

10. Explore the possibility of establishing a Global Risk Organisation (GRO)

There is currently no international or global body that is coordinating work on global risks with a potentially infinite impact. The following areas would benefit from global coordination:

– Probability estimations
– Early warning systems,
– Global coordination of solutions
– Legal development

In addition, and probably equally important, is the fact that a body set up to deal with such challenges could also ensure that the links between them could be better understood.

A first step could be to establish a centre for global risks and opportunities,[669] focusing initially only on knowledge-gathering and development of proposals, and with no mandate to implement any solutions.

Endnotes

[1] http://www.cnbc.com/id/100915696

[2] http://en.wikipedia.org/wiki/Global_catastrophic_risks

[3] http://www.merriam-webster.com/dictionary/risk

[4] http://en.wikipedia.org/wiki/Probability_density_function

[5] Dickson, David CM. Insurance risk and ruin. Cambridge University Press 2005.

http://books.google.se/books?id=9zPOMMqJXcUC&printsec=frontcover&source=gbs_ge_summary_r&redir_esc=y#v=onepage&q&f=false

[6] http://www.itl.nist.gov/div898/handbook/eda/section3/eda352.htm

[7] A recent example is IPCC WGII Summary for policy makers. In this report http://ipcc-wg2.gov/AR5/ IPCC acknowledges the need to include low-probability high-impact scenarios: "assessment of the widest possible range of potential impacts, including low-probability outcomes with large consequences, is central to understanding the benefits and trade-offs of alternative risk management actions." Yet nothing is included in the report about impacts above 4 degrees.

[8] As an infinite impact by definition can't have happened before , models are needed.

[9] Making Sense of Uncertainty Why uncertainty is part of science http://www.lse.ac.uk/CATS/Media/SAS012-MakingSenseofUncertainty.pdf

[10] Pinker, Steven. The better angels of our nature: The decline of violence in history and its causes. Penguin UK, 2011.

[11] Giddens, Anthony. "Risk and responsibility." The modern law review 62.1 (1999): 1-10.

[12] http://blogs.ei.columbia.edu/2012/01/09/evolutionary-psychology-of-climate-change/

http://www-ee.stanford.edu/~hellman/Breakthrough/book/chapters/frankenhaeuser.html

"The challenge now is to help people extend their attachments, their loyalties, and their engagement, to include people outside their own narrow circle, their own country, their own imminent future. This global reorientation is a prerequisite for changing the present fatal course of development."

[13] http://www-ee.stanford.edu/~hellman/Breakthrough/book/chapters/frankenhaeuser.html

[14] Two of the most famous "optimists", who tend to look at only the parts of the probability distribution that support their opinion, are the Danish writer Bjorn Lomborg and the British journalist Matt Ridley. While scientists in the areas he writes about constantly refute Lomborg, his message of optimism is well received by many policy makers and business leaders. https://www.ma.utexas.edu/users/davis/375/reading/sciam.pdf

Ridley cherrypicks data and tends to avoid the probability that we will see significant warming. http://www.mattridley.co.uk/blog/the-probable-net-benefits-of-climate-change-till-2080.aspxhttp://www.rationaloptimist.com/

[15] Climate Impacts: http://www.ipcc.ch/report/ar5/wg2/

Pandemics: http://www.cmu.edu/dietrich/sds/docs/fischhoff/AF-GPH.pdf

Nuclear war: http://www.ippnw.org/nuclear-famine.html

[16] http://news.stanford.edu/news/2003/september24/tellerobit-924.html

[17] http://www.fas.org/sgp/othergov/doe/lanl/docs1/00329010.pdf

[18] While the LA-602 document is relatively well-known its final paragraph is often forgotten. The scientists say: "However, the complexity of the argument and the absence of satisfactory experimental foundations makes further work on the subject highly desirable."

[19] Since Teller's calculations the science has developed and is now clear that the main nuclear threat that potentially could threaten human civilisation is a full nuclar war and the consequenses that this could result in from effects like a nuclear winter.

[20] For an overview of positive and negative aspects of nanotechnology see for example Drexler, Eric and Pamlin, Dennis (2013): "Nano-solutions for the 21st century. Unleashing the fourth technological revolution" http://www.oxfordmartin.ox.ac.uk/downloads/academic/201310Nano_Solutions.pdf

[21] This is true for utopias ranging from Plato's Republic, via Thomas More's book Utopia, to Edward Bellamy's Looking Backward and William Morris' News from Nowhere.

[22] See next chapter for the methodology.

[23] A list of organisations and studies that discuss challenges that threaten human civilisation can be found here: http://en.wikipedia.org/wiki/Global_catastrophic_risks

[24] The number two billion was established during the workshop in Oxford and is not an exact number. Further research is needed to establish a better understanding of thresholds that can result in an infinite impact, depending on what challenge resulted in the two billion impact and how the estimate for an infinite impact was assumed to be between 0.01% and 10%.

[25] The definition is based on the definition used by Jared Diamond: http://www.jareddiamond.org/Jared_Diamond/Collapse.html

[26] For examples see the recently established Centre for Study of Existential Risk at Cambridge. It is an interdisciplinary research centre focused on the study of human extinction-level risks that may emerge from technological advance

[27] E.g. HBR blog about "black swans": http://blogs.hbr.org/2010/09/the-competing-black-swans-of-s/ and The Guardian about "perfect storms" http://www.theguardian.com/environment/earth-insight/2014/apr/03/ipcc-un-climate-change-perfect-storm-zombie-oil

[28] http://www.economist.com/node/18744401

[29] http://e360.yale.edu/feature/living_in_the_anthropocene_toward_a_new_global_ethos/2363/

[30] http://www.nickbostrom.com/existential/risks.html

[31] https://www.youtube.com/watch?v=VjZyOTES6iQ

[32] http://en.wikipedia.org/wiki/Long_tail

[33] http://en.wikipedia.org/wiki/Human

[34] Mammals have an average species lifespan from origin to extinction of about 1 million years, but that will not necessarily apply to humans today because of factors like local climate change or new species in the same ecological niche. The dinosaurs were around for 135 million years and if we are intelligent, there are good chances that we could live for much longer.

[35] http://en.wikipedia.org/wiki/Human_embryogenesis

[36] These four points are slightly rewritten versions of a list of Nick Bostrom's in the text "Existential Risks: Analyzing Human Extinction Scenarios and Related Hazards" http://www.nickbostrom.com/existential/risks.html. Note that these four points were originally developed for "existential risks", those that threaten the extinction of intelligent life originating on Earth or the permanent destruction of its potential for desirable future development.

[37] Posner, Richard A. Catastrophe: Risk and Response. Oxford University Press, 2004,

[38] http://en.wikipedia.org/wiki/Value_of_life

[39] http://yosemite.epa.gov/EE%5Cepa%5Ceed.nsf/webpages/MortalityRiskValuation.html

[40] Posner, Richard A. Catastrophe: risk and response. Oxford University Press, 2004. Loc 2363

[41] http://webarchive.nationalarchives.gov.uk/+/http:/www.hm-treasury.gov.uk/sternreview_index.htm

[42] William Nordhaus , The Stern Review on the Economics of Climate Change http://www.econ.yale.edu/~nordhaus/homepage/stern_050307.pdf

[43] http://www.res.org.uk/view/art3Apr08Features.html

[44] Nordhaus, William D. The Climate Casino: Risk, Uncertainty, and Economics for a Warming World. Yale University Press, 2013. Loc 2895

[45] Nordhaus, William D. The Climate Casino: Risk, Uncertainty, and Economics for a Warming World. Yale University Press, 2013. Loc 2895

[46] Nordhaus, William D. The Climate Casino: Risk, Uncertainty, and Economics for a Warming World. Yale University Press, 2013. Loc 3176

[47] Timothy M. Lenton, Juan-Carlos Ciscar: Integrating tipping points into climate impact assessments. Springer Netherlands 2013-04-01 http://link.springer.com/article/10.1007%2Fs10584-012-0572-8

[48] Carl Sagan use 10 million years in: Sagan, Carl (1983). "Nuclear war and climatic catastrophe: Some policy implications". Foreign Affairs 62: 275, and The Blackwell's Concise Encyclopedia of Ecology and other sources provide an estimate of about 1 million years for mammals. http://eu.wiley.com/WileyCDA/WileyTitle/productCd-0632048727.html

[49] One billion years is used by Bruce E. Tonn in the paper Obligations to future generations and acceptable risks of human extinction: " Futures 41.7 (2009): 427-435.

[50] In Japan in Japan the life expectancy at age zero, that is, at birth (LEB), is 83 years. In 2010 the world LEB was 67.2.

[51] This is based on a low estimate for the planet's population as far out as current projections are made, 2100. http://esa.un.org/wpp/ Looking further into the far future, beyond 500 years, it is likely that humanity will have expanded into space and have a much larger population.

[52] Posner, Richard A. Catastrophe: Risk and Response. Oxford University Press, 2004, Loc 2378

[53] http://www.esa.int/Our_Activities/Space_Science/Herschel/How_many_stars_are_there_in_the_Universe?

[54] http://www.existential-risk.org/concept.pdf

[55] McSharry, Patrick E., and David Orrell (2009). A Systems Approach to Forecasting. FORESIGHT: The International Journal of Applied Forecasting, referring to Wolfram, Stephen (2002):A new kind of science, V Wolfram media. http://www.irgc.org/wp-content/uploads/2013/06/McSharry-OrrellMcSharry2009foresight.pdf

[56] From A Systems Approach to Forecasting" by David Orrell and Patrick McSharry, http://www.irgc.org/wp-content/uploads/2013/06/McSharry-OrrellMcSharry2009foresight.pdf
referring to Wolfram, S. (2002). A New Kind of Science. https://www.wolframscience.com/

[57] A possible infinite threshold could be compared with the two events that are often cited as the world's worst wars and anthropogenic disasters: the second world war, with 40-71 million dead (1.7-3.1% of the world's population) and the Mongol Conquests, 1206-1368, with 30 million dead (7.5% of the global total). See: http://en.wikipedia.org/wiki/List_of_wars_and_anthropogenic_disasters_by_death_toll

[58] The number two billion was established during workshops arranged during the process and is not an exact number. Further research is needed to establish a better understanding of thresholds that can result in an infinite impact. The number of people dead is only one factor and different global risks are likley to have very different thresholds.

[59] HSE 2001. Reducing Risks, Protecting People – HSE's Decision-Making Process, 2001.
http://www.hse.gov.uk/risk/theory/r2p2.pdf

[60] Bedford, Paul, Millard, Stephen and Jing Yang, Assessing operational risk in CHAPS Sterling: a simulation approach (2004).

[61] SO 16732-1, Fire Safety Engineering – Guidance on Fire Risk Assessment, International Organization for Standardization, Geneva, Switzerland, 2012.

[62] http://en.wikipedia.org/wiki/ALARP

[63] http://www.risktec.co.uk/media/43520/risk%20criteria%20-%20when%20is%20low%20enough%20good%20enough%20-%20saudi.pdf

[64] SO 16732-1, Fire Safety Engineering – Guidance on Fire Risk Assessment, International Organization for Standardization, Geneva, Switzerland, 2012.

[65] An example of a concept that helped increase the focus on an important category is Genocide, which was introduced by Raphael Lemkin. http://en.wikipedia.org/wiki/Genocide

[66] E.g. Vinso, Joseph D. "A Determination of the Risk of Ruin." Journal of Financial and Quantitative Analysis 14.01 (1979): 77-100.

[67] E.g. Reed, Christina. Earth Science: Decade by Decade. Infobase Publishing, 2009.

[68] Culpitt, Ian. Social policy and risk. Sage, 1999.

[69] http://en.wikipedia.org/wiki/Jared_Diamond

[70] The methodology applied in this study has been developed by Dennis Pamlin from Global Challenges Foundation and Stuart Armstrong, James Martin Research Fellow, Future of Humanity Institute at the University of Oxford together with Seth Baum, Executive Director of the Global Catastrophic Risk Institute and affiliate researcher at the Center for Research on Environmental Decisions, Columbia University.

[71] The literature overview is included as Appendix 1.

[72] http://gcrinstitute.org/people/

[73] http://cred.columbia.edu/about-cred/people/affiliated-researchers/sethbaum/

[74] http://wokinfo.com/

[75] http://scholar.google.com

[76] See Appendix 1 for the full overview.

[77] http://highlycited.com/

[78] Specifically, publications selected met one or more of the following criteria, and were more likely to be selected if they met multiple criteria: (1) published in a peer-reviewed journal or academic press; (2) authored by scholars of established distinction; (3) published in an authoritative popular media outlet; (4) authored by journalists or other non-academic writers of established distinction; (5) highly cited by other scholars; (6) thorough in presentation and analysis.

[79] http://www.existential-risk.org/concept.pdf

[80] Climate change is a good example. Very little is done on the infinite impacts where global warming would result in an average temperature rise of 6°C or more.

[81] The list of organisations is included as Appendix 2.

[82] http://gcrinstitute.org/organization-directory/

[83] The 19 organisations are:
Brookings
http://www.brookings.edu/research#topics/
Bulletin of the Atomic Scientists
http://thebulletin.org/
CSER
http://cser.org/emerging-risks-from-technology/
Center for International Security and Cooperation
http://cisac.stanford.edu/
Club of Rome
http://www.clubofrome.org/
Council on Foreign Relations
http://www.cfr.org/issue/
Federation of American Scientists
http://www.fas.org/programs
Future of Humanity Institute
http://www.fhi.ox.ac.uk/research/research-areas/
Global Catastrophic Risk Institute
http://gcrinstitute.org/research/
Institute for Defence Studies and Analyses
http://www.idsa.in/topics
International Risk Governance Council
http://www.irgc.org/issues/
Lifeboat Foundation
http://lifeboat.com/ex/programs
Nuclear Threat Initiative
http://www.nti.org/
Saving Humanity from Homo Sapiens
http://shfhs.org/whatarexrisks.html
Skoll Global Threats Fund
http://www.skollglobalthreats.org/
Stimson Center
http://www.stimson.org/programs/
Risk Response Network
http://forumblog.org/communities/risk-response-network/
World Economic Forum
http://www.weforum.org/reports/global-risks-2014-report
Tower Watson
http://www.towerswatson.com/en/Insights/IC-Types/Survey-Research-Results/2013/10/Extreme-risks-2013

[84] http://www.towerswatson.com/en/Insights/IC-Types/Survey-Research-Results/2013/10/Extreme-risks-2013

[85] Page 50 http://www3.weforum.org/docs/WEF_GlobalRisks_Report_2014.pdf

[86] Page 50 http://www3.weforum.org/docs/WEF_GlobalRisks_Report_2014.pdf

[87] http://www.weforum.org/reports/global-risks-2014-report

[88] http://www.iea.org/newsroomandevents/pressreleases/2011/november/name,20318,en.html
http://www.ipcc.ch/pdf/assessment-report/ar4/wg3/ar4-wg3-chapter12.pdf

[89] Wolfe, Nathan. The viral storm: the dawn of a new pandemic age. Macmillan, 2011.

[90] This includes any research that indicates the probabilities are much lower than first believed.

[91] For a list of other overviews please see Annex 1

[92] See Podsiadlowski, Ph, et al. "The rates of hypernovae and gamma-ray bursts: implications for their progenitors." The Astrophysical Journal Letters 607.1 (2004).

[93] See Coleman, Sidney, and Frank De Luccia. "Gravitational effects on and of vacuum decay." Physical Review D 21.12 (1980): 3305-3315.

[94] See Iliopoulos, John, et al. "Study of potentially dangerous events during heavy-ion collisions at the LHC: report of the LHC safety study group." Vol. 1. CERN (2003). http://194.109.159.7/cern/20101116222315/cdsweb.cern.ch/record/613175/files/p1.pdf

[95] See for instance "Solar storm Risk to the North American electric grid", Lloyds (2013).

[96] See Bennett, Oliver. "Cultural pessimism: Narratives of decline in the postmodern world." Edinburgh University Press (2001).

[97] See Klare, Michael T. "Resource wars: The new landscape of global conflict." Macmillan (2001).

[98] See for instance the genocides listed in White, Matthew "Atrocitology: Humanity's 100 Deadliest Achievements." Canongate Books (2011).

[99] See for instance the exponents on different power laws of natural and other disasters in Hanson, Robin.

"Catastrophe, social collapse, and human extinction." Global Catastrophic Risks 1 (2008).

[100] See the damage and impacts listed in Carr, Jeffrey. "Inside cyber warfare: Mapping the cyber underworld." O'Reilly Media, Inc. (2011). http://www.amazon.co.uk/Inside-Cyber-Warfare-Mapping-Underworld/dp/1449310044

[101] See the medium estimate in United Nations. Dept. of Economic and Social Affairs. "World Population to 2300." New York: United Nations, Department of Economic and Social Affairs, (2004). https://www.un.org/esa/population/publications/longrange2/WorldPop2300final.pdf

[102] See the article " Delayed biological recovery from extinctions throughout the fossil record" by James W. Kirchner & Anne Weil in Nature: http://seismo.berkeley.edu/~kirchner/reprints/2000_34_delayed_recovery.pdf

[103] Attractor: a set of physical properties towards which a system tends to evolve. Strange attractor: a complicated set with a fractal structure. http://en.wikipedia.org/wiki/Attractor

http://www.stsci.edu/~lbradley/seminar/attractors.html

[104] Folke, C., S. R. Carpenter, B. Walker, M. Scheffer, T. Chapin, and J. Rockström. 2010. Resilience thinking: integrating resilience, adaptability and transformability. Ecology and Society 15(4): 20. [online] URL: http://www.ecologyandsociety.org/vol15/iss4/art20/

[105] We define use Jared Diamods definition of collapse for "end of civilisation", but focus only in global impacts, so the definiton is "A drastic decrease in human population size and/or political/economic/social complexity, globally for an extended time." http://www.jareddiamond.org/Jared_Diamond/Collapse.html

[106] See Korhonen, Jouni, and Thomas P. Seager. "Beyond eco-efficiency: a resilience perspective." Business Strategy and the Environment 17.7 (2008): 411-419.

[107] Maher, Timothy M., and Seth D. Baum. "Adaptation to and recovery from global catastrophe." Sustainability 5.4 (2013): 1461-1479.

[108] Such as the Svalbard Global Seed Vault.

[109] The fall of the Roman Empire, for instance, resulted in the loss of many technologies and techniques: Aiyar, Shekhar, Carl-Johan Dalgaard, and Omer Moav. "Technological progress and regress in pre-industrial times." Journal of Economic Growth 13.2 (2008): 125-144.

[110] See Ćirković, Milan M., Anders Sandberg, and Nick Bostrom. "Anthropic shadow: Observation selection effects and human extinction risks." Risk analysis 30.10 (2010): 1495-1506.

[111] Organisations working with global challenges included in the process where challenges were selected. Below: example of organisations where information was gathered from, in alphabetical order:

http://cass.cssn.cn/

http://www.cfr.org

http://cser.org

http://www.thebulletin.org

http://www.fhi.ox.ac.uk

http://www.sipri.org

http://www.skollglobalthreats.org

http://www.stockholmresilience.org

http://www.un.org/en/sc/

http://www.weforum.org/issues/global-risks

Examples of relevant literature:

Nick Bostrom & Milan Cirkovic Eds.(Oxford University Press, 2008) Global Catastrophic Risks.

Martin Rees, "Our final century", Random House, 2003. Martin, James, 2007. The Meaning of the 21st Century. New York: Riverhead Penguin.

Posner, Richard, 2004. Catastrophe: Risk and Response. Oxford: Oxford University Press.

[112] See appendix X for participants at workshops

[113] http://en.wikipedia.org/wiki/Climate_change

[114] See the IPCC's Fifth Assessment Report.

[115] See Chateld, Chris. "Model uncertainty, data mining and statistical inference." JR Statist. Soc. A 158 (1995): 419-466, and for climate change models specifically, see Pindyck, Robert S. "Climate Change Policy: What do the models tell us?" No. w19244. National Bureau of Economic Research (2013).

[116] See Stern, Nicholas. "The structure of economic modeling of the potential impacts of climate change: grafting gross underestimation of risk onto already narrow science models." Journal of Economic Literature 51.3 (2013): 838-859.

[117] See Weitzman, Martin L. "Tail-Hedge Discounting and the Social Cost of Carbon." Journal of Economic Literature 51.3 (2013): 873-882.

[118] See Bodman, Roger W., Peter J. Rayner, and David J. Karoly. "Uncertainty in temperature projections reduced using carbon cycle and climate observations." Nature Climate Change (2013).

[119] Some of the severe consequences of this are explored in the World Bank report "Turn Down The Heat: why a 4°C warmer world must be avoided" (2012).

[120] See Lynas, Mark. "Six degrees: Our future on a hotter planet." HarperCollins UK (2008), also summarised by its author in a Guardian article "Six steps to hell," and Schneider, Stephen. "The worst-case scenario." Nature 458.7242 (2009): 1104-1105.

[121] See Zimov, Sergey A., Edward AG Schuur, and F. Stuart Chapin III. "Permafrost and the global carbon budget." Science 312.5780 (2006): 1612-1613.

[122] See Malhi, Yadvinder, et al. "Exploring the likelihood and mechanism of a climate-change-induced dieback of the Amazon rainforest." Proceedings of the National Academy of Sciences 106.49 (2009): 20610-20615.

[123] There are arguments that climate change is structurally unsuited to treaty-based emissions curbs; see Barrett, Scott. "Climate treaties and approaching catastrophes." Journal of Environmental Economics and Management (2013).

[124] The World Bank has estimated that the cost of adapting to 2°C climate change would be of the order of $70-100 billion a year (source: Economics of Adaptation to Climate Change, World Bank).

[125] See Lynas, Mark. "Six degrees: Our future on a hotter planet." HarperCollins UK (2008), also summarised by its author in a Guardian article "Six steps to hell."

[126] See for instance the open letter from the Partnership for a Secure America: "Thirty-Eight Leading U.S. National Security Experts Urge Action on International Climate Change Initiatives" (2013).

[127] See Weiss, Harvey, and Raymond Bradley; "What drives societal collapse?" The Anthropology of Climate Change: An Historical Reader (2013): 151-154.

[128] See Patz, Jonathan A., et al.; "Global climate change and emerging infectious diseases." JAMA: the journal of the American Medical Association 275.3 (1996): 217-223.

[129] See Benton, Michael J., and Richard J. Twitchett. "How to kill (almost) all life: the end-Permian extinction event." Trends in Ecology & Evolution 18.7 (2003): 358-365.

[130] See Shepherd, J. G.: "Geoengineering the climate: science, governance and uncertainty." Royal Society, (2009).

[131] See Robock, Alan, et al: "Benefits, risks, and costs of stratospheric geoengineering." Geophysical Research Letters 36.19 (2009).

[132] See Brovkin, Victor, et al.: "Geoengineering climate by stratospheric sulfur injections: Earth system vulnerability to technological failure." Climatic Change 92.3-4 (2009): 243-259.

[133] See Baum, Seth D., Timothy M. Maher Jr, and Jacob Haqq-Misra.: "Double catastrophe: intermittent stratospheric geoengineering induced by societal collapse." Environment Systems & Decisions (2013): 1-13.

[134] http://www.nature.com/ncomms/2014/140225/ncomms4304/full/ncomms4304.html

http://www.geomar.de/en/news/article/climate-engineering-geringes-potential-grosse-nebenwirkungen/

[135] See Tetlock, Philip E.: "Expert political judgment: How good is it? How can we know?" Princeton University Press (2005).

[136] See the Carbon Tracker Initiative report: "Unburnable carbon 2013: Wasted capital and stranded assets."

[137] These figures are broadly in line with those of Meinshausen, Malte, et al.: "Greenhouse-gas emission targets for limiting global warming to 2°C." Nature 458.7242 (2009): 1158-1162.

[138] See for instance the Scientific American report: "400 PPM: Carbon Dioxide in the Atmosphere Reaches Prehistoric Levels."

[139] See Lüthi, Dieter, et al.: "High-resolution carbon dioxide concentration record 650,000–800,000 years before present." Nature 453.7193 (2008): 379-382.

[140] See the IPCC's Fourth Assessment Report.

[141] See the Independent report "China agrees to impose carbon targets by 2016."

[142] See the UN Millennium Development Goal database "Carbon dioxide emissions (CO2), thousand metric tons of CO2 (CDIAC)."

[143] See the announcement by the Chinese Bureau of Meteorology: "National Low Carbon Day logo and slogan officially announced."

[144] See the Warsaw Climate Change Conference Press Release "UN Climate Change Conference in Warsaw keeps governments on a track towards 2015 climate agreement."

[145] See the UNFCCC's "Private Sector Initiative - database of actions on adaptation."

[146] See Buchanan, James M.: "Externality." Economica 29.116 (1962): 371-384.

[147] See the IPCC's Fifth Assessment Report.

[148] See the Global Challenge Foundation's explanation "About the Global Risk and Opportunity Indicator."

[149] See the Warsaw Climate Change Conference Press Release "UN Climate Change Conference in Warsaw keeps governments on a track towards 2015 climate agreement."

[150] http://en.wikipedia.org/wiki/Public_good

[151] See Feldman, Allan M., and A. M. Feldman.: "Welfare economics and social choice theory." Boston: Martinus Nijhoff (1980).

[152] See the Warsaw Climate Change Conference Press Release "UN Climate Change Conference in Warsaw keeps governments on a track towards 2015 climate

agreement."

[153] "The so-called "Warsaw International Mechanism for Loss and Damage" will from next year commit developed nations to provide expertise and potentially aid to countries hit by climate-related impacts. [...] However, the vague wording fell short of the kind of detailed commitments on additional funding and the commitment to compensation that many developing nations had been seeking." (source: Business Green: "COP 19: Warsaw climate deal finalised as deadlock broken").

[154] See for instance Bulkeley, Harriet, and Peter Newell.: "Governing climate change." Routledge (2010).

[155] See the National Research Council: "Abrupt Impacts of Climate Change: Anticipating Surprises." Washington, DC: The National Academies Press (2013).

[156] See NASA's "GISS Surface Temperature Analysis."

[157] See the IPCC's Fourth Assessment Report.

[158] See the IPCC's Fifth Assessment Report.

[159] See the IUCN's Red List of Threatened Species.

[160] See McManus, J. F., et al.: "Collapse and rapid resumption of Atlantic meridional circulation linked to deglacial climate changes." Nature 428.6985 (2004): 834-837.

[161] See Schuur, Edward AG, et al.: "Vulnerability of permafrost carbon to climate change: Implications for the global carbon cycle." BioScience 58.8 (2008): 701-714.

[162] See Archer, David.: "Methane hydrate stability and anthropogenic climate change." Biogeosciences Discussions 4.2 (2007): 993-1057.

[163] For example, as climate warms, the destabilization of the West Antarctic ice sheet could raise sea level rapidly, with serious consequences for coastal communities.

[164] http://simple.wikipedia.org/wiki/Nuclear_war

[165] For an analysis of the possibility of accidental nuclear war between Russia and the USA, see Barrett, Anthony M., Seth D. Baum, and Kelly Hostetler.: "Analyzing and Reducing the Risks of Inadvertent Nuclear War Between the United States and Russia." Science & Global Security 21.2 (2013): 106-133.

[166] Hellman, Martin E.: "How risky is nuclear optimism?." Bulletin of the Atomic Scientists 67.2 (2011): 47-56.

[167] See Lundgren, Carl.: "What are the odds? Assessing the probability of a nuclear war." The Nonproliferation Review 20.2 (2013): 361-374.

[168] A 1979 study by the United States Office of Technology Assessment, "The Effects of Nuclear War," estimated 20-160 million immediate casualties from a full-scale nuclear war.

[169] Currently estimated at around 17,000 (source: SIPRI yearbook 2013).

[170] Though it has been argued that scientists, under pressure from governments and industry, have systematically underestimated the deleterious global impact of radiation. See Perrow, Charles.: "Nuclear denial: From Hiroshima to Fukushima." Bulletin of the Atomic Scientists 69.5 (2013): 56-67.

[171] The seminal American paper was Turco, Richard P., et al.: "Nuclear winter: global consequences of multiple nuclear explosions." Science 222.4630 (1983): 1283-1292. The Soviet Union was working on similar simulations; see for instance Peterson, Jeannie.: "The aftermath: The human and ecological consequences of nuclear war." New York: Pantheon (1983).

[172] See Mills, Michael J., et al.: "Massive global ozone loss predicted following regional nuclear conflict." Proceedings of the National Academy of Sciences 105.14 (2008): 5307-5312.

[173] Though some have argued for a significant climate effect of the nuclear explosions themselves, see Fujii, Yoshiaki.: "The role of atmospheric nuclear explosions on the stagnation of global warming in the mid 20th century." Journal of Atmospheric and Solar-Terrestrial Physics 73.5 (2011): 643-652.

[174] There is (fortunately) very little empirical evidence on the impact of nuclear bombs on cities. Hiroshima suffered a firestorm, while Nagasaki did not – and both cities and nuclear weapons are very different now from what they were in 1945.

[175] See Toon, Owen B., et al.: "Atmospheric effects and societal consequences of regional scale nuclear conflicts and acts of individual nuclear terrorism." Atmospheric Chemistry and Physics 7.8 (2007): 1973-2002, and Robock, Alan, Luke Oman, and Georgiy L. Stenchikov.: "Nuclear winter revisited with a modern climate model and current nuclear arsenals: Still catastrophic consequences." Journal of Geophysical Research: Atmospheres (1984–2012) 112.D13 (2007).

[176] Arsenals have been reduced, but there remain over 17,000 nuclear warheads in the world's arsenals (source: SIPRI yearbook 2013), down from a peak of some 68,000 in 1983, still more than enough to trigger a nuclear winter.

[177] See Toon, Owen B., et al.: "Atmospheric effects and societal consequences of regional scale nuclear conflicts and acts of individual nuclear terrorism." Atmospheric Chemistry and Physics 7.8 (2007): 1973-2002, and Helfand, Ira.: "NUCLEAR FAMINE: TWO BILLION PEOPLE AT RISK?." International Physicians for the Prevention of Nuclear War (2013).

[178] Maher, Timothy M., and Seth D. Baum.: "Adaptation to and recovery from global catastrophe." Sustainability 5.4 (2013): 1461-1479.

[179] See the later part of the scenario in Tonn, Bruce, and Donald MacGregor.: "A singular chain of events." Futures 41.10 (2009): 706-714.

[180] A synthesis blogpost by Carl Shulman of the Future of Humanity Institute puts the risk of extinction, given civilisation collapse, at no more than 10%.

[181] See Tetlock, Philip E.: "Expert political judgment: How good is it? How can we know?" Princeton University Press (2005).

[182] See the official Remarks by Ambassador Susan E. Rice, U.S. Permanent Representative to the United Nations, at the Security Council Stakeout.

[183] "North Korean nuclear test draws anger, including from China" (Reuters).

[184] See the Security Council Resolution 2087 (2013).

[185] See the description of the sanctions in the Security Council Committee established pursuant to resolution 1718.

[186] See the States Parties of the Nuclear Non-Proliferation Treaty (NPT).

[187] See North Korean security challenges: a net assessment. International Institute for Strategic Studies, 2011, Chapter 5.

[188] See North Korean security challenges: a net assessment. International Institute for Strategic Studies, 2011, Chapter 6.

[189] See North Korean security challenges: a net assessment. International Institute for Strategic Studies, 2011, Chapter 8.

[190] See Chanlett-Avery, Emma, and Mi Ae Taylor.: "North Korea: US Relations, Nuclear Diplomacy, and Internal Situation." Congressional Research Service, Library of Congress, 2010.

[191] See Bennett, Bruce W., and Jennifer Lind.: "The Collapse of North Korea: Military Missions and Requirements." International Security 36.2 (2011): 84-119.

[192] Even the 1968 capture by North Korea of the USS Pueblo did not reignite conflict (see Armbrister, Trevor.: "A Matter of Accountability: The True Story of the Pueblo Affair." Globe Pequot, 2004).

[193] See the Norwegian Ministry of Foreign Affairs: "Conference: Humanitarian Impact of Nuclear weapons."

[194] This conference took place 13-14 February of 2014 http://www.sre.gob.mx/en/index.php/humanimpact-nayarit-2014

[195] See The 1983 War Scare: "The Last Paroxysm" of the Cold War Part I, The 1983 War Scare: "The Last Paroxysm" of the Cold War Part II, and The 1983 War Scare: "The Last Paroxysm" of the Cold War Part III.

[196] See The 1983 War Scare: "The Last Paroxysm" of the Cold War Part III.

[197] An extensive but certainly not exhaustive list can be found at http://en.wikipedia.org/wiki/List_of_military_nuclear_accidents.

[198] See especially the role of Vasili Arkhipov in preventing the conflict from going nuclear – a role that was only revealed in 2002 (source: Roberts, Priscilla, ed. "Cuban Missile Crisis: The Essential Reference Guide." ABC-CLIO, 2012).

[199] See Scott Shane, writing in the Baltimore Sun: "The Nuclear War that Almost Happened in 1983" (August 31, 2003).

[200] See the PBS report on the incident.

[201] Errors of a different kind happened in the early days of the Cold War, when simple game theory models were used to argue for a nuclear first strike (source: Kaku, Michio, and Daniel Axelrod. "To win a nuclear war: the Pentagon's secret war plans." Black Rose Books Ltd., 1987).

[202] Some have modelled the nuclear standoff as a "perceptual dilemma," where misperception of the adversary is the main cause of arms races (source: Plous, Scott.: "The nuclear arms race: prisoner's dilemma or perceptual dilemma?." Journal of Peace Research 30.2 (1993): 163-179).

[203] See Barrett, Anthony M., Seth D. Baum, and Kelly Hostetler.: "Analyzing and Reducing the Risks of Inadvertent Nuclear War Between the United States and Russia." Science & Global Security 21.2 (2013): 106-133.

[204] See Barrett, Anthony M., Seth D. Baum, and Kelly Hostetler.: "Analyzing and Reducing the Risks of Inadvertent Nuclear War Between the United States and Russia." Science & Global Security 21.2 (2013): 106-133.

[205] See Podvig, Pavel.: "Reducing the risk of an Accidental Launch." Science and Global Security 14.2-3 (2006): 75-115.

[206] See Intriligator, Michael D., and Dagobert L. Brito.: "Accidental nuclear war: a significant issue for arms control." Current Research on Peace and Violence 11.1/2 (1988): 14-23.

[207] See Ayson, Robert.: "After a terrorist nuclear attack: Envisaging catalytic effects." Studies in Conflict & Terrorism 33.7 (2010): 571-593.

[208] See Hellman, Martin E.: "How risky is nuclear optimism?." Bulletin of the Atomic Scientists 67.2 (2011): 47-56.

[209] See Shanteau, James.: "Competence in experts: The role of task characteristics." Organizational behavior and human decision processes 53.2 (1992): 252-266.

[210] See also Mosher, David E., et al.: Beyond the Nuclear Shadow. "A Phased Approach for Improving Nuclear Safety and US Russian Relations." No. RAND/MR-1666-NSRD. RAND CORP SANTA MONICA CA, 2003.

[211] See the Report of the Open-ended Working Group to develop proposals to take forward multilateral nuclear disarmament negotiations for the achievement and maintenance of a world without nuclear weapons.

[212] See the text of the Treaty on the Non-Proliferation of Nuclear Weapons.

[213] Treaty Between the United States of America and the Union of Soviet Socialist Republics on the Elimination of Their Intermediate-Range and Shorter-Range Missiles.

[214] Treaty Between the United States of America and the Union of Soviet Socialist Republics on the Reduction and Limitation of Strategic Offensive Arms.

[215] Treaty Between the United States of America and the Russian Federation On Strategic Offensive Reductions.

[216] The Treaty between the United States of America and the Russian Federation on Measures for the Further Reduction and Limitation of Strategic Offensive Arms also known as the New START Treaty.

[217] See Sovacool, Benjamin K. "Contesting the future of nuclear power: a critical global assessment of atomic energy." World Scientific, 2011.

[218] Helfand, Ira.: "Nuclear Famine: Two Billion People at Risk?" International Physicians for the Prevention of Nuclear War (2013).

[219] See for instance Robock, Alan, Luke Oman, and Georgiy L. Stenchikov.: "Nuclear winter revisited with a modern climate model and current nuclear arsenals: Still catastrophic consequences." Journal of Geophysical Research: Atmospheres (1984–2012) 112.D13 (2007), Toon, Owen B., et al. "Atmospheric effects and societal consequences of regional scale nuclear conflicts and acts of individual nuclear terrorism." Atmospheric Chemistry and Physics 7.8 (2007): 1973-2002, and Stenke, A., et al. "Climate and chemistry effects of a regional scale nuclear conflict." Atmospheric Chemistry and Physics Discussions 13.5 (2013): 12089-12134.

[220] Helfand, Ira.: "An assessment of the extent of projected global famine resulting from limited, regional nuclear war." Royal Soc. Med, London (2007).

[221] See Özdoğan, Mutlu, Alan Robock, and Christopher J. Kucharik.: "Impacts of a nuclear war in South Asia on soybean and maize production in the Midwest United States." Climatic Change 116.2 (2013): 373-387.

Xia, Lili, and Alan Robock.: "Impacts of a nuclear war in South Asia on rice production in Mainland China." Climatic Change 116.2 (2013): 357-372.

[223] See Stommel H, Stommel E.: "Volcano Weather: The Story of 1816, The Year without a Summer." Seven Seas Press: Newport (1983).

[224] See the European External Action Service Joint Plan of Action (24 November 2013).

[225] See the report of the Director General of the IAEA (8 November 2011).

[226] See Security Council Resolution 1737 (2006).

[227] See the text of the Treaty on the Non-Proliferation of Nuclear Weapons.

[228] See for instance President Kennedy's quote during the third Nixon-Kennedy presidential debate, October 13, 1960: "There are indications because of new inventions, that 10, 15, or 20 nations will have a nuclear capacity, including Red China, by the end of the Presidential office in 1964."

[229] "More Than 40 Countries Could Have Nuclear Weapons Know-How, IAEA Chief ElBaradei Warns" (Nuclear Threat Initiative).

[230] http://en.wikipedia.org/wiki/List_of_states_with_nuclear_weapons

[231] http://en.wikipedia.org/wiki/Ecological_collapse

[232] See Pimm, Stuart L., et al.: "The future of biodiversity." Science 269 (1995): 347-347.

[233] See Rockström, Johan, et al.: "Planetary boundaries: exploring the safe operating space for humanity." Ecology and society 14.2 (2009).

[234] See Barnosky, Anthony D., et al.: "Approaching a state shift in Earth's biosphere." Nature 486.7401 (2012): 52-58.

[235] See Ehrlich, Paul R., and Anne H. Ehrlich.: "Can a collapse of global civilization be avoided?." Proceedings of the Royal Society B: Biological Sciences 280.1754 (2013).

[236] See Galaz, Victor, et al.: "Global environmental governance and planetary boundaries: An introduction." Ecological Economics 81 (2012): 1-3.

[237] See Dol, Marcel, ed.: "Recognizing the intrinsic value of animals: beyond animal welfare." Uitgeverij Van Gorcum (1999).

[238] See Dasgupta, Partha.: "Human well-being and the natural environment." OUP Catalogue (2001).

[239] See the author's blog post: "Water, food or energy: we won't lack them.," summarising the current evidence.

[240] See "2013 World Hunger and Poverty Facts and Statistics." World Hunger Education Service (2013).

[241] Maher, Timothy M., and Seth D. Baum.: "Adaptation to and recovery from global catastrophe." Sustainability 5.4 (2013): 1461-1479.

[242] See Dullinger, Stefan, et al.: "Europe's other debt crisis caused by the long legacy of future extinctions." Proceedings of the National Academy of Sciences 110.18 (2013): 7342-7347.

[243] G8 2007 Environment Ministers Meeting.

[244] See Pimm, Stuart L., et al. "The future of biodiversity." Science 269 (1995): 347-347.

[245] See Jones-Walters, Lawrence, and Ivo Mulder: "Valuing nature: The economics of biodiversity." Journal for Nature Conservation 17.4 (2009): 245-247.

[246] See the UN-mandated "Millennium Ecosystem Assessment, Ecosystems and Human Well-being: Synthesis" (2005).

[247] See Bottrill, Madeleine C., et al.: "Is conservation triage just smart decision making?" Trends in Ecology & Evolution 23.12 (2008): 649-654.

[248] See Fox, Jonathan A., and Lloyd David Brown, eds.: "The struggle for accountability: the World Bank, NGOs, and grassroots movements." MIT Press (1998).

[249] http://www.esri.com/news/releases/11-4qtr/gis-cloud-featured-at-eye-on-earth-summit.html

[250] See Microsoft's press release "Eye on Earth Enables Cloud-Based Environmental Data Sharing" (2011).

[251] "The main objective of the MyOcean2 project is to deliver and operate a rigorous, robust and sustainable Ocean Monitoring and Forecasting system of the GMES Marine Service (OMF/GMS) to users for all marine applications: maritime safety, marine resources, marine and coastal environment and climate, seasonal and weather forecasting." (Source the MyOcean2 website).

[252] See the "Communication from the (European) commission to the council, concerning a consultation on Fishing Opportunities for 2014."

[253] The famous "tragedy of the commons." See Garrett Hardin. "The Tragedy of the Commons" Science 162.3859 (1968): 1243-1248.

[254] See Schlager, Edella, and Elinor Ostrom. "Property-rights regimes and natural resources: a conceptual analysis." Land economics (1992): 249-262.

[255] See Frank, Kenneth T., et al. "Trophic cascades in a formerly cod-dominated ecosystem." Science 308.5728 (2005): 1621-1623.

[256] See the IUCN's Red List of Threatened Species.

[257] See Zalasiewicz, Jan, et al. "Are we now living in the Anthropocene?." GSA Today 18.2 (2008): 4.

[258] See Barnosky, Anthony D., et al.: "Approaching a state shift in Earth's biosphere." Nature 486.7401 (2012): 52-58.

[259] See Dol, Marcel, ed.: "Recognising the intrinsic value of animals: beyond animal welfare." Uitgeverij Van Gorcum (1999).

[260] http://en.wikipedia.org/wiki/Pandemic

[261] See Hanson, Robin.: "Catastrophe, social collapse, and human extinction." Global Catastrophic Risks 1 (2008): 357.

[262] See Asmussen, Søren. "Steady-State Properties of of GI/G/1." Applied Probability and Queues (2003): 266-301.

[263] Possessing neither variance nor mean.

[264] This explains why governments and international organisations seem to over-react to pandemics (such as the swine 'flu scare). Though any single pandemic is unlikely to cause a large number of casualties, there is always the small risk that it could get out of hand and kill millions.

[265] There is always a probability that the power law will not hold for future pandemics – but the majority of the risk is concentrated in scenarios where it does.

[266] See Hanson, Robin.: "Catastrophe, social collapse, and human extinction." Global Catastrophic Risks 1 (2008): 357.

[267] Source: EM-DAT, The International Disaster Database.

[268] See Jeffs, Benjamin.: "A clinical guide to viral haemorrhagic fevers: Ebola, Marburg and Lassa." Tropical Doctor 36.1 (2006): 1-4.

[269] See the WHO Factsheet 99 on Rabies.

[270] See Arroll, Bruce.: "Common cold." Clinical evidence 2011 (2011).

[271] See "Stages of HIV." U.S. Department of Health & Human Services.

[272] See Bouvier, Nicole M., and Peter Palese.: "The biology of influenza viruses." Vaccine 26 (2008): D49-D53.

[273] See for instance Risk Management Solutions' pandemic model, overviewed in "The RMS® Influenza Pandemic Risk Model."

[274] SARS (Severe), for instance, started in China and spread to 17 other countries, including Canada (source: Lung Disease & Respiratory Health Center, SARS: Timeline of an Outbreak).

[275] See Riley, Lee W., et al.: "Slum health: diseases of neglected populations." BMC international health and human rights 7.1 (2007): 2.

[276] Brazil alone is estimated to have over 50 uncontacted tribes (source: Survival International).

[277] Maher, Timothy M., and Seth D. Baum.: "Adaptation to and recovery from global catastrophe." Sustainability 5.4 (2013): 1461-1479.

[278] See the WHO Interim Guidance "Pandemic Influenza Risk Management."

[279] See the WHO guidance document "Pandemic influenza preparedness and response."

[280] See Trifonov, Vladimir, Hossein Khiabanian, and

Raul Rabadan.: "Geographic dependence, surveillance, and origins of the 2009 influenza A (H1N1) virus." New England Journal of Medicine 361.2 (2009): 115-119.

[281] See the WHO Sixty Fourth World Health Assembly "Resolutions and Decisions," resolution WHA64.5.

[282] See the WHO International Health Regulations (2005) "Alert, response, and capacity building under the International Health Regulations (IHR)."

[283] See the "Report of the Review Committee on the Functioning of the International Health Regulations (2005) in Relation to Pandemic (H1N1) 2009." Geneva, World Health Organization (2011).

[284] See Kerkhove, Maria D., et al.: "Estimating age-specific cumulative incidence for the 2009 influenza pandemic: a meta-analysis of A (H1N1) pdm09 serological studies from 19 countries." Influenza and Other Respiratory Viruses (2013).

[285] Report in Nature by Maryn McKenna, "Antibiotic resistance: The last resort."

[286] See Alchon, Suzanne Austin. "A Pest in the Land: New World Epidemics in a Global Perspective." University of New Mexico Press (2003).

[287] See Rothschild, Bruce M..: "History of syphilis." Clinical infectious diseases: an official publication of the Infectious Diseases Society of America 40.10 (2005): 1454–63

[288] See Lawn, Stephen D., and Zumla, Alimuddin I.: "Tuberculosis," The Lancet 378.9785 (2011): 57-72.

[289] See the World Health Organization Fact Sheet No 104 on Tuberculosis.

[290] See Harrison, J. W., and T. A. Svec: "The beginning of the end of the antibiotic era? Part II. Proposed solutions to antibiotic abuse." Quintessence international (Berlin, Germany: 1985) 29.4 (1998): 223.

[291] See Mathew, Alan G., Robin Cissell, and S. Liamthong: "Antibiotic resistance in bacteria associated with food animals: a United States perspective of livestock production." Foodborne pathogens and disease 4.2 (2007): 115-133.

[292] See the final summary from the Skoll Global Threats Fund "Wrap up from Epihack."

[293] See Sridhar, Saranya, et al.: "Cellular immune correlates of protection against symptomatic pandemic influenza." Nature Medicine 19.10 (2013): 1305-1312.

[294] See Taubenberger, Jeffery K., and David M. Morens.: "1918 Influenza: the mother of all pandemics." Rev Biomed 17 (2006): 69-79.

[295] See Valleron, Alain-Jacques, et al.: "Transmissibility and geographic spread of the 1889 influenza pandemic." Proceedings of the National Academy of Sciences 107.19 (2010): 8778-8781.

[296] See the WHO report Ten things you need to know about pandemic influenza.

[297] See Dawood, Fatimah S., et al.: "Estimated global mortality associated with the first 12 months of 2009 pandemic influenza A H1N1 virus circulation: a modelling study." The Lancet infectious diseases 12.9 (2012): 687-695.

[298] See Merler, Stefano, et al.: "Containing the accidental laboratory escape of potential pandemic influenza viruses." BMC medicine 11.1 (2013): 252.

[299] Report in Nature by Declan Butler, "Work resumes on lethal flu strains."

[300] From 2004 to 2010, 639 release reports were reported to the Centers for Disease Control (CDC), 11 of them reporting laboratory-acquired infections (source: Henkel, Richard D., Thomas Miller, and Robbin S. Weyant. Monitoring Select Agent Theft, Loss and Release Reports in the United States—2004-2010. Appl Biosaf 17 (2012):171-180.)

[301] It is suspected that the 1977-1978 Russian 'Flu epidemic was caused by a laboratory incident in Russia or northern China (source: NPR's interview with Professor John Oxford at St. Bart's and the Royal London Hospital).

[302] See Pennington, Hugh.: Smallpox and bioterrorism. Bulletin of the World Health Organization 81.10 (2003): 762-767.

[303] See Klotz, L. C., and E. J. Sylvester.: The unacceptable risks of a man-made pandemic. Bulletin of the Atomic Scientists 7 (2012).

[304] The highest level of biosecurity.

[305] A Marburg virus laboratory-acquired infection at the Vector facility in the Soviet Union in 1990, a foot-and-mouth disease virus escape from the Pirbright facility in England, and a SARS virus laboratory-acquired infection from a BSL-4-rated biosafety cabinet in a Taiwan laboratory.

[306] See the Towers Watson poll of global insurance executives on the most worrying extreme risks facing the insurance industry.

[307] See the CDC's report Taubenberger, Jeffery K., and David M. Morens.: 1918 Influenza: the mother of all pandemics. Rev Biomed 17 (2006): 69-79.

[308] See the World Health Organization Global Influenza Programme: Pandemic influenza preparedness and response: a WHO guidance document. World Health Organisation (2009).

[309] See Merton, Robert K.: Bureaucratic structure and personality. Social forces 18.4 (1940): 560-568, and Turner, Marlene E., and Anthony R. Pratkanis: Twenty-five years of groupthink theory and research: Lessons from the evaluation of a theory. Organizational Behavior and Human Decision Processes 73.2 (1998): 105-115.

[310] http://en.wikipedia.org/wiki/Economic_collapse http://en.wikipedia.org/wiki/Societal_collapse

[311] See Helbing, Dirk.: Globally networked risks and how to respond. Nature 497.7447 (2013): 51-59.

[312] See Anders Sandberg, Nick Beckstead, Stuart Armstrong.: "Defining systemic risk." Report from the FHI-Amlin Systemic Risk of Risk Modelling Collaboration. Oxford University (2014).

[313] See Gunderson, Lance H.: "Ecological resilience--in theory and application." Annual review of ecology and systematics (2000): 425-439, and Kambhu, John, Scott Weidman, and Neel Krishnan. Part 3: Systemic risk in ecology and engineering. Economic Policy Review 13.2 (2007).

[314] See De Bandt, Olivier, and Philipp Hartmann.: Systemic risk: A survey. ECB Working Paper No. 35 (2000).

[315] See Rinaldi, Steven M., James P. Peerenboom, and Terrence K. Kelly.: Identifying, understanding, and analyzing critical infrastructure interdependencies. Control Systems, IEEE 21.6 (2001): 11-25.

[316] See Homer-Dixon, Thomas.: Complexity Science. Oxford Leadership Journal 2.1 (2011): 15.

[317] See Allen, Franklin, and Douglas Gale.: Financial contagion. Journal of political economy 108.1 (2000): 1-33.

[318] See Buldyrev, Sergey V., et al.: Catastrophic cascade of failures in interdependent networks. Nature 464.7291 (2010): 1025-1028.

[319] See Vespignani, Alessandro.: Predicting the behavior of techno-social systems. Science 325.5939 (2009): 425.

[320] See Goldin, Ian, and Mike Mariathasan.: The Butterfly Defect: How Globalization Creates Systemic Risks, and What to Do about It. Princeton University Press (2014).

[321] See Goldin, Ian, and Tiffany Vogel.: Global governance and systemic risk in the 21st century: lessons from the financial crisis. Global Policy 1.1 (2010): 4-15.

[322] See Korhonen, Jouni, and Thomas P. Seager.: Beyond eco-efficiency: a resilience perspective. Business Strategy and the Environment 17.7 (2008): 411-419.

[322] See J. Doyne Farmer.: Toward better quantitative models of systemic risk. Presentation at Institute for New Economic Thinking (2010).

[323] See the Lloyds Insurance report "Solar storm risk to the North American electric grid." (2013).

[324] See Barro, Robert J., and Xavier Sala-i-Martin.: Economic growth and convergence across the United States. No. w3419. National Bureau of Economic Research (1990).

[325] See Hanson, Robin.: Catastrophe, social collapse, and human extinction. Global Catastrophic Risks 1 (2008): 357.

[326] See for instance the temporary collapse of the Albanian state in 1997 over poorly regulated investment pyramid schemes: Jarvis, Christopher.: The rise and fall of Albania's pyramid schemes. Finance and Development 37.1 (2000): 46-49.

[327] See Acemoglu, Daron, James A. Robinson, and Dan Woren.: Why nations fail: the origins of power, prosperity, and poverty. Vol. 4. New York: Crown Business (2012).

[328] See the LSE press release Research centre to study risks to financial system launched at LSE (2013).

[330] See Ang, Andrew, and Francis A. Longstaff.: Systemic sovereign credit risk: Lessons from the US and Europe. Journal of Monetary Economics (2013).

[331] See for instance Brunnermeier, Markus K., and Lasse Heje Pedersen.: Market liquidity and funding liquidity. Review of Financial studies 22.6 (2009): 2201-2238.

[332] See for instance Calomiris, Charles W., and Joseph R. Mason.: Fundamentals, panics, and bank distress during the depression. American Economic Review (2003): 1615-1647.

[333] See the IMF working paper Systemic Risk Monitoring ("SysMo") Toolkit—A User Guide (2013).

[334] See for instance Moorhouse, Andrew.: An introduction to financial soundness indicators. Monetary & Financial Statistics (2004).

[335] See for instance Baldacci, E., McHugh, J. and Petrova, I.: Measuring Fiscal Vulnerabilities and Fiscal Stress: A Proposed Set of Indicators, IMF Working Paper 11/94 (2011).

[336] See for instance Hamilton, James D., and Raul Susmel.: Autoregressive conditional heteroskedasticity and changes in regime. Journal of Econometrics 64.1 (1994): 307-333.

[337] See for instance Gray, Dale F., and Andreas A. Jobst.: Modelling systemic financial sector and sovereign risk. Sveriges Riksbank Economic Review (2011): 68-97.

[338] See Citigroup's paper 2013 Outlook and Strategies (2013) and the Financial Post news report by David Pett: Three geopolitical risks investors should keep an eye on in 2014 (2013).

[339] Used by such diverse bodies as the US Department of Energy (source: the US Department of Energy's Cost Estimating Guide (2011)) and AACE (Association for the Advancement of Cost Engineering) International (source: AACE Recommended Practice No. 56R-08 Cost Estimate Classification System (2012)).

[340] http://en.wikipedia.org/wiki/Impact_event

[341] See Jablonski, David, and W. G. Chaloner.: Extinctions in the Fossil Record [and Discussion]. Philosophical Transactions of the Royal Society of London. Series B: Biological Sciences 344.1307 (1994): 11-17.

[342] See Collins, Gareth S., H. Jay Melosh, and Robert A. Marcus.: Earth Impact Effects Program: A Web-based computer program for calculating the regional environmental consequences of a meteoroid impact on Earth. Meteoritics & planetary science 40.6 (2005): 817-840. Input data: Projectile Diameter: 5000m, Projectile Density: 2600 kg/m3, Impact Velocity: 17.00 km/s, Impact Angle: 45 degrees.

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[344] The effects of various sizes of impacts have been estimated in Atkinson, Harry, Crispin Tickell, and David Williams.: Report of the task force on potentially hazardous near-Earth objects. (2000).

[345] See for instance Collins, Gareth S., H. Jay Melosh, and Robert A. Marcus.: Earth Impact Effects Program: A Web-based computer program for calculating the regional environmental consequences of a meteoroid impact on Earth. Meteoritics & planetary science 40.6 (2005): 817-840, Jeffers, S. V., et al.: Near-Earth object velocity distributions and consequences for the Chicxulub impactor. Monthly Notices of the Royal Astronomical Society 327.1 (2001): 126-132, and Board, Space Studies.: Defending Planet Earth: Near-Earth Object Surveys and Hazard Mitigation Strategies. National Academies Press (2010). A summary of the last paper can be found at The Danger from Asteroid impact.

[346] See the NASA press release NASA Spacecraft Reactivated to Hunt for Asteroids.

[347] See NASA's Near Earth Objects Discovery Statistics.

[348] See Harris, Alan.: What Spaceguard did. Nature 453.7199 (2008): 1178-1179.

[349] http://www.nature.com/nature/journal/v453/n7199/fig_tab/4531178a_F2.html

[350] See Hall, Christopher D., and I. Michael Ross.: Dynamics and control problems in the deflection of Near-Earth Objects. Adv. Astronaut. Sci 67.640 (1997): 1-18.

[351] Some are more optimistic than others: "An impact can be predicted in advance in ways that remain imperfect but are much more reliable than predictions of earthquakes or even storms, and the components of technology exist - at affordable costs given the consequences of an actual impact - to move any threatening object away and avoid the disaster altogether." (source: Chapman, Clark R. "The hazard of near-Earth asteroid impacts on earth." Earth and Planetary Science Letters 222.1 (2004): 1-15.) See also NASA's report to Congress "Near-Earth Object Survey and Deflection Analysis of Alternatives" (2007).

[352] See 2013 World Hunger and Poverty Facts and Statistics. World Hunger Education Service (2013).

[353] See Maher, Timothy M., and Seth D. Baum.: Adaptation to and recovery from global catastrophe. Sustainability 5.4 (2013): 1461-1479.

[354] Report of the Task Force on potentially hazardous Near-Earth Objects. http://spaceguardcentre.com/wp-content/uploads/2014/04/full_report.pdf

[355] See Ćirković, Milan M., Anders Sandberg, and Nick Bostrom.: Anthropic shadow: Observation selection effects and human extinction risks. Risk analysis 30.10 (2010): 1495-1506.

[356] See NASA's press release on the meteor, Additional Details on the Large Fireball Event over Russia on Feb. 15, 2013.

[357] See Borovička, Jiří, et al.: The trajectory, structure and origin of the Chelyabinsk asteroidal impactor. Nature (2013).

[358] See Chyba, Christopher F., Paul J. Thomas, and Kevin J. Zahnle.: The 1908 Tunguska explosion: atmospheric disruption of a stony asteroid. Nature 361.6407 (1993): 40-44.

[359] See for instance the Russian reaction: PM Medvedev Says Russian Meteorite KEF-2013 Shows "Entire Planet" Vulnerable.

[360] See the Space Research Institute of Russian Academy of Science report Deflecting Hazardous Asteroids from Collision with the Earth by Using Small Asteroids.

[361] See for instance Collins, Gareth S., H. Jay Melosh, and Robert A. Marcus.: Earth Impact Effects Program: A Web-based computer program for calculating the regional environmental consequences of a meteoroid impact on Earth. Meteoritics & planetary science 40.6 (2005): 817-840, and Jeffers, S. V., et al.: Near-Earth object velocity distributions and consequences for the Chicxulub impactor. Monthly Notices of the Royal Astronomical Society 327.1 (2001): 126-132.

[362] See Hall, Christopher D., and I. Michael Ross.: Dynamics and control problems in the deflection of Near-Earth Objects. Adv. Astronaut. Sci 67.640 (1997): 1-18.

[363] See NASA's Asteroid Watch, Asteroid 2013 TV135 - A Reality Check.

[364] The effects of various sizes of impacts have been estimated in Atkinson, Harry, Crispin Tickell, and David Williams.: Report of the task force on potentially hazardous near-Earth objects. (2000).

[365] See Live Science, The Odds of Dying.

[366] See Scientific American, United Nations to Adopt Asteroid Defense Plan.

[367] See Brown, P. G., et al.: A 500-kiloton airburst over Chelyabinsk and an enhanced hazard from small impactors. Nature (2013).

[368] See Glasstone, Samuel.: The effects of nuclear weapons. US Department of Defense (1964).

[369] See NBC's report Third time's the charm: SpaceX launches big commercial satellite.

[370] See Hall, Christopher D., and I. Michael Ross.: Dynamics and control problems in the deflection of Near-Earth Objects. Adv. Astronaut. Sci 67.640 (1997): 1-18.

[371] See NASA News, NASA Announces New Homes for Space Shuttle Orbiters After Retirement.

[372] See NASA Report Launching into History.

[373] http://en.wikipedia.org/wiki/Supervolcano

[374] See Reichow, Marc K., et al.: The timing and extent of the eruption of the Siberian Traps large igneous province: Implications for the end-Permian environmental crisis. Earth and Planetary Science Letters 277.1 (2009): 9-20, and Benton, Michael J., and M. J. Benton.: When life nearly died: the greatest mass extinction of all time. Vol. 5. London: Thames & Hudson (2003).

[375] See Shen, Shu-zhong, et al.: Calibrating the end-Permian mass extinction. Science 334.6061 (2011): 1367-1372.

[376] Kerr, Richard A.: Mega-Eruptions Drove the Mother of Mass Extinctions. Science 342.6165 (2013): 1424-1424.

[377] A partial list can be found on Wikipedia: http://en.wikipedia.org/wiki/Timetable_of_major_worldwide_volcanic_eruptions.

[378] See Newhall, Christopher G., and Stephen Self.: The Volcanic Explosivity Index (VEI): an estimate of explosive magnitude for historical volcanism. Journal of Geophysical Research: Oceans (1978–2012) 87.C2 (1982): 1231-1238.

[379] See Aspinall, W., et al.: Volcano hazard and exposure in GDRFF priority countries and risk mitigation measures-GFDRR Volcano Risk Study. Bristol: Bristol University Cabot Institute and NGI Norway for the World Bank: NGI Report 20100806.2011 (2011).

[380] See Mason, Ben G., David M. Pyle, and Clive Oppenheimer.: The size and frequency of the largest explosive eruptions on Earth. Bulletin of Volcanology 66.8 (2004): 735-748.

[381] See Stephen Self and Stephen Blake, "Consequences of Explosive Super-eruptions" ELEMENTS , VOL . 4, 41–46: http://chuma.cas.usf.edu/~juster/GLY2030-F09/supervolcanoes-self%20and%20blake.pdf

[382] See Zielinski, G. A., et al.: Potential atmospheric impact of the Toba Mega-Eruption 71,000 years ago. Geophysical Research Letters 23.8 (1996): 837-840.

[383] It is estimated that the largest volcanic eruptions have an energy greater than 1021 Joules (source: Mason, Ben G., David M. Pyle, and Clive Oppenheimer.: The size and frequency of the largest explosive eruptions on Earth. Bulletin of Volcanology 66.8 (2004): 735-748.), while the largest nuclear device ever exploded had a yield of around 2x1017 Joules (source: Adamsky, Viktor, and Yuri Smirnov.: Moscow's Biggest Bomb: The 50-Megaton Test of October 1961. Cold War International History Project Bulletin 4 (1994): 19-21.).

[384] See Scarpa, Roberto.: Predicting volcanic eruptions. Science 293.5530 (2001): 615-616.

[385] Sparks, Stephen. Super-eruptions: Global effects and future threats, report of a Geological Society of London working group. Geological Society, 2005.

[386] See 2013 World Hunger and Poverty Facts and Statistics. World Hunger Education Service (2013).

[387] Maher, Timothy M., and Seth D. Baum.: Adaptation to and recovery from global catastrophe. Sustainability 5.4 (2013): 1461-1479.

[388] See Sparks, S. & Self. S. et al., 2005: Super-eruptions: global effects and future threats: Report of a Geological Society of London working group. http://www.geo.mtu.edu/~raman/VBigIdeas/Supereruptions_files/Super-eruptionsGeolSocLon.pdf

[389] http://en.wikipedia.org/wiki/Volcanic_Explosivity_Index
http://volcanoes.usgs.gov/images/pglossary/vei.php

[390] See Ćirković, Milan M., Anders Sandberg, and Nick Bostrom.: Anthropic shadow: Observation selection effects and human extinction risks. Risk analysis 30.10 (2010): 1495-1506.

[391] See Lane, Christine S., Ben T. Chorn, and Thomas C. Johnson.: Ash from the Toba supereruption in Lake Malawi shows no volcanic winter in East Africa at 75 ka. Proceedings of the National Academy of Sciences 110.20 (2013): 8025-8029.

[392] See Zielinski, G. A., et al.: Potential atmospheric impact of the Toba Mega-Eruption 71,000 years ago. Geophysical Research Letters 23.8 (1996): 837-840.

[393] See Yoichi Nakamura, Shigeo Aramaki and Eisuke Fujita, Japan's Volcanic Disaster Mitigation Initiatives: Activities of the Commission on Mitigation of Volcanic Disasters, the Volcanological Society of Japan, Technical

Note of the National Research Institute for Earth Science and Disaster Prevention 380 (2013).

[394] See Barnes, Gina L.: Origins of the Japanese Islands: The New "Big Picture". Nichibunken Japan Review (2003): 3-50.

[395] See Nakamura, Y., Fukushima, K., Jin, X., Ukawa, M., Sato, T., and Hotta, Y.: Mitigation Systems by Hazard Maps, Mitigation Plans, and Risk Analyses Regarding Volcanic Disasters in Japan. J. Disaster Research, 3-4, (2007) 297-304.

[396] See Omer, Haim, and Nahman Alon.: The continuity principle: A unified approach to disaster and trauma. American Journal of Community Psychology 22.2 (1994): 273-287.

[397] See Smith, Robert B. et al.: Discoveries and breakthroughs from integrative analysis of Yellowstone science revealing new tectonic-volcanic models and a new assessment of earthquake-volcano hazards. Geological Society of America Abstracts with Programs. Vol. 45. No. 7. 2013.

[398] See Earthquake-hazards Scenario for a M7 Earthquake on the Salt Lake City Segment of the Wasatch Fault Zone, Utah. No. 111. Utah Geological Survey (2004).

[399] See the Towers Watson poll of global insurance executives on the most worrying extreme risks facing the insurance industry.

[400] See Merton, Robert K.: Bureaucratic structure and personality. Social forces 18.4 (1940): 560-568, and Turner, Marlene E., and Anthony R. Pratkanis.: Twenty-five years of groupthink theory and research: Lessons from the evaluation of a theory. Organizational Behavior and Human Decision Processes 73.2 (1998): 105-115.

[401] See Kerr, Richard A.: Mega-Eruptions Drove the Mother of Mass Extinctions. Science 342.6165 (2013): 1424-1424.

[402] A partial list can be found on Wikipedia: http://en.wikipedia.org/wiki/Timetable_of_major_worldwide_volcanic_eruptions.

[403] See Reichow, Marc K., et al.: The timing and extent of the eruption of the Siberian Traps large igneous province: Implications for the end-Permian environmental crisis. Earth and Planetary Science Letters 277.1 (2009): 9-20, and Benton, Michael J., and M. J. Benton.: When life nearly died: the greatest mass extinction of all time. Vol. 5. London: Thames & Hudson (2003).

[404] See Shen, Shu-zhong, et al.: Calibrating the end-Permian mass extinction. Science 334.6061 (2011): 1367-1372.

[405] http://en.wikipedia.org/wiki/Synthetic_biology

[406] See Schmidt, Markus, ed.: Synthetic biology: industrial and environmental applications. Wiley-Blackwell (2012).

[407] Making Synthetic biology into an "epistemic" risk: the risk might be minute or huge, it's unclear at present. See Sahlin, Nils-Eric, and Johannes Persson.: Epistemic risk: the significance of knowing what one does not know. Future risks and risk management. Springer Netherlands (1994) 37-62.

[408] The decision to lift the moratorium on potentially dangerous gain of function 'flu research was taken by the researchers themselves (source: Declan Butler: Work resumes on lethal flu strains, Nature News).

[409] See Schmidt, Markus.: Diffusion of synthetic biology: a challenge to biosafety. Systems and synthetic biology 2.1-2 (2008): 1-6.

[410] See Wilson, Grant.: Minimizing global catastrophic and existential risks from emerging technologies through international law. Available at SSRN 2179094 (2012).

[411] See Kelle, Alexander.: Ensuring the security of synthetic biology—towards a 5P governance strategy. Systems and synthetic biology 3.1-4 (2009): 85-90, and Bernauer, Hubert, et al.: Technical solutions for biosecurity in synthetic biology. Industry Association Synthetic Biology, Munich, Germany (2008).

[412] Though see some of the suggestions in Garfinkel, Michele S., et al.: Synthetic genomics: options for governance. Industrial Biotechnology 3.4 (2007): 333-365.

[413] See Dennis, Carina.: The bugs of war. Nature 411.6835 (2001): 232-235.

[414] See Smith, Bruce D., and Mark Nesbitt.: The emergence of agriculture. New York: Scientific American Library (1995).

[415] See Tucker, Jonathan B.: The Current Bioweapons Threat. Biopreparedness and Public Health. Springer Netherlands (2013) 7-16.

[416] With corporations targeting each other's biological products, for instance.

[417] A risk the US Government is already taking seriously; see for instance President George W. Bush's April 2004 Biodefense for the 21st Century initiative. The threat of bioterrorism is also prominent in the 2007 report Mapping the Global Future: Report of the National Intelligence Council's 2020 Project.

[418] The World Health Organization estimates that many countries and institutions lack oversight of such dual use technologies (source: Report of the WHO Informal Consultation on Dual Use Research of Concern, World Health Organization).

[419] See Baum, Seth, and Grant Wilson.: The Ethics of Global Catastrophic Risk from Dual-Use Bioengineering. Ethics in Biology, Engineering and Medicine 4 (2013).

[420] Attempts at containing such a leak may not be successful; see Merler, Stefano, et al.: Containing the accidental laboratory escape of potential pandemic influenza viruses. BMC medicine 11.1 (2013): 252.

[421] See for instance Hwang, In Young, et al.: Reprogramming Microbes to Be Pathogen-Seeking Killers. ACS synthetic biology (2013).

[422] Brazil alone is estimated to have over 50 uncontacted tribes (source: Survival International).

[423] See Top U.S. Disease Fighters Warn of New Engineered Pathogens but Call Bioweapons Doomsday Unlikely. Global Security Newswire (2005).

[424] Maher, Timothy M., and Seth D. Baum.: Adaptation to and recovery from global catastrophe. Sustainability 5.4 (2013): 1461-1479.

[425] See the later part of the scenario in Tonn, Bruce, and Donald MacGregor.: A singular chain of events. Futures 41.10 (2009): 706-714.

[426] See Guan, Zheng-Jun, et al.: Biosafety Considerations of Synthetic Biology in the International Genetically Engineered Machine (iGEM) Competition. BioScience 63.1 (2013): 25-34.

[427] See Wired Magazine's feature article Genome at Home: Biohackers Build Their Own Labs.

[428] Such as Bernauer, Hubert, et al.: Technical solutions for biosecurity in synthetic biology. Industry Association Synthetic Biology, Munich, Germany (2008).

[429] See Lenox, Michael J., and Jennifer Nash.: Industry self-regulation and adverse selection: a comparison across four trade association programs. Business strategy and the environment 12.6 (2003): 343-356.

[430] See Butler, Declan.: Work resumes on lethal flu strains. Nature 493.7433 (2013): 459-459.

[431] See Imai, Masaki, et al.: Experimental adaptation of an influenza H5 HA confers respiratory droplet transmission to a reassortant H5 HA/H1N1 virus in ferrets. Nature 486.7403 (2012): 420-428, and Herfst, Sander, et al.: Airborne transmission of influenza A/H5N1 virus between ferrets. Science 336.6088 (2012): 1534-1541.

[432] See Butler, Declan.: Fears grow over lab-bred flu. Nature 480 (2011): 421-422.

[433] See Fouchier, R. A., et al.: Pause on avian flu transmission research. Science 335.6067 (2012): 400-401.

[434] See Sherrill, Michelle.: Self-Serving Bias. American Psychologist 41: 954-969 (2008).

[435] See for instance the London Independent: Leading scientists condemn decision to continue controversial research into deadly H5N1 bird-flu virus.

[436] See the Report of the WHO Informal Consultation on Dual Use Research of Concern.

[437] See Imai, Masaki, et al.: Experimental adaptation of an influenza H5 HA confers respiratory droplet transmission to a reassortant H5 HA/H1N1 virus in ferrets. Nature 486.7403 (2012): 420-428, and Herfst, Sander, et al.: Airborne transmission of influenza A/H5N1 virus between ferrets. Science 336.6088 (2012): 1534-1541.

[438] See the WHO report Responsible life sciences research for global health security: a guidance document. (2010).

[439] See Jackson, Ronald J., et al.: Expression of mouse interleukin-4 by a recombinant ectromelia virus suppresses cytolytic lymphocyte responses and overcomes genetic resistance to mousepox. Journal of virology 75.3 (2001): 1205-1210.

[440] See Rosengard, Ariella M., et al.: Variola virus immune evasion design: expression of a highly efficient inhibitor of human complement. Proceedings of the National Academy of Sciences 99.13 (2002): 8808-8813.

[441] See Cello, Jeronimo, Aniko V. Paul, and Eckard Wimmer.: Chemical synthesis of poliovirus cDNA: generation of infectious virus in the absence of natural template. Science 297.5583 (2002): 1016-1018.

[442] See Tumpey, Terrence M., et al.: Characterization of the reconstructed 1918 Spanish influenza pandemic virus. Science 310.5745 (2005): 77-80.

[443] See Gibson, Daniel G., et al.: Complete chemical synthesis, assembly, and cloning of a Mycoplasma genitalium genome. Science 319.5867 (2008): 1215-1220.

[444] See Zhang, Ying, et al.: H5N1 hybrid viruses bearing 2009/H1N1 virus genes transmit in guinea pigs by respiratory droplet. Science 340.6139 (2013): 1459-1463.

[445] The Human Fatality and Economic Burden of a Man-made Influenza Pandemic.

[446] See Drexler, K. Eric.: Engines of Creation: the Coming Era of Nanotechnology. Fourth Estate (1990).

[447] See Drexler, K. Eric.: Radical Abundance: How a Revolution in Nanotechnology Will Change Civilization. Public Affairs (2013).

[448] See Freitas, Robert A., and Ralph Charles Merkle.: Kinematic self-replicating machines. Georgetown, TX: Landes Bioscience/Eurekah. com (2004).

[449] See Committee to Review the National Nanotechnology Initiative.: A matter of size: Triennial review of the National Nanotechnology Initiative. (2006).

[450] According to the CIA World Factbook.

[451] See Roco, Mihail C., and William S. Bainbridge.: Societal implications of nanoscience and nanotechnology: Maximizing human benefit. Journal of Nanoparticle Research 7.1 (2005): 1-13.

[452] See the report of the Center for Responsible Nanotechnology,: Dangers of Molecular Manufacturing.

[453] See Drexler, K. Eric.: Radical Abundance: How a Revolution in Nanotechnology Will Change Civilization. PublicAffairs (2013).

[454] See Barber, Kevin, et al.: Nanotechnology for Uranium Separations and Immobilization. Advances in Materials Science for Environmental and Nuclear Technology: Ceramic Transactions 107 (2010): 177.

[455] See Gubrud, Mark Avrum.: Nanotechnology and international security. Fifth Foresight Conference on Molecular Nanotechnology (1997).

[456] See Altmann, Jürgen.: Military uses of nanotechnology: perspectives and concerns. Security Dialogue 35.1 (2004): 61-79.

[457] See the Oxford Martin School publication by Drexler, K. Eric and Pamlin, Dennis: Nano-solutions for the 21st Century, (2013).

[458] See Wilson, Grant.: Minimizing global catastrophic and existential risks from emerging technologies through international law. Available at SSRN 2179094 (2012).

[459] See Drexler, K. Eric.: Engines of Creation: the Coming Era of Nanotechnology. Fourth Estate (1990).

[460] See Phoenix, Chris, and Eric Drexler.: Safe exponential manufacturing. Nanotechnology 15.8 (2004): 869.

[461] See Freitas Jr, Robert A.: Some limits to global ecophagy by biovorous nanoreplicators, with public policy recommendations. Foresight Institute (2000).

[462] Such as computer viruses today, which endure despite efforts at eradication, but don't threaten the system as a whole.

[463] See Leary, Scott P., Charles Y. Liu, and Michael LJ Apuzzo.: Toward the emergence of nanoneurosurgery: Part III-Nanomedicine: Targeted nanotherapy, nanosurgery, and progress toward the realization of nanoneurosurgery. Neurosurgery 58.6 (2006): 1009-1026..

[464] See the later part of the scenario in Tonn, Bruce, and Donald MacGregor.: A singular chain of events. Futures 41.10 (2009): 706-714.

[465] See Tetlock, Philip E.: Expert political judgment: How good is it? How can we know? Princeton University Press (2005).

[466] See Lewandowski, Bartosz, et al.: Sequence-specific peptide synthesis by an artificial small-molecule machine. Science 339.6116 (2013): 189-193.

[467] See Freitas, Robert A., and Ralph Charles Merkle.: Kinematic self-replicating machines. Georgetown, TX: Landes Bioscience/Eurekah. com (2004).

[468] Defined by Eric Drexler as a "device able to guide chemical reactions by positioning reactive molecules with atomic precision."

[469] See Vugt, Gert Van.: The Killer Idea: How Some Gunslinging Anarchists Held Freedom of Speech at Gunpoint. Proceedings of the eLaw Conference 3D Printing: Destiny, Doom or Dream (2013).

[470] See the report of the Center for Responsible Nanotechnology, Dangers of Molecular Manufacturing.

[471] See Excell, John, and Stuart Nathan.: The rise of additive manufacturing. The Engineer (2010).

[472] The gun designer, Cody Wilson, who describes himself as a crypto-anarchist, said his plans to make the design available were "about liberty" (source: BBC News).

[473] See Drexler, K. Eric.: Radical Abundance: How a Revolution in Nanotechnology Will Change Civilization. PublicAffairs (2013).

[474] See Drexler, K. Eric.: Engines of Creation: the Coming Era of Nanotechnology. Fourth Estate (1990).

[475] See Nanostart's presentation at the EuroNanoForum 2013, Dublin: Venture Capital Investments in Nanotech (2013).

[476] See Nanostart's newsletter, A space elevator would be a tremendous benefit for humankind (2012).

[477] See Levine, Michael E., and Jennifer L. Forrence.: Regulatory capture, public interest, and the public agenda: Toward a synthesis. Journal of Law, Economics, & Organization 6 (1990): 167-198.

[478] See the Congressional Research Service report, Nanotechnology: a Policy Primer (2013).

[479] Nano-replicator: A system able to build copies of itself when provided with raw materials and energy

[480] http://en.wikipedia.org/wiki/Artificial_intelligence

[481] See Armstrong, Stuart, and Kaj Sotala. 2012.: How We're Predicting AI—or Failing To. In Beyond AI: Artificial Dreams, edited by Jan Romportl, Pavel Ircing, Eva Zackova, Michal Polak, and Radek Schuster, 52–75

[482] See Chalmers, David, The singularity: A philosophical analysis. Journal of Consciousness Studies 17.9-10 (2010): 9-10.

[483] See Muehlhauser, Luke, and Anna Salamon.: Intelligence explosion: Evidence and import. Singularity Hypotheses. Springer Berlin Heidelberg (2012) 15-42.

[484] See Yudkowsky, Eliezer.: Intelligence Explosion Microeconomics. Technical report 2013-1 Berkeley, CA: Machine Intelligence Research Institute (2013).

[485] See Wilson, Grant.: Minimizing global catastrophic and existential risks from emerging technologies through international law. Available at SSRN 2179094 (2012).

[486] See Omohundro, Stephen M.: The basic AI drives. Frontiers in Artificial Intelligence and applications 171 (2008): 483.

[487] See Muehlhauser, Luke, and Louie Helm.: Intelligence Explosion and Machine Ethics. In Singularity Hypotheses: A Scientific and Philosophical Assessment, edited by Amnon Eden, Johnny Søraker, James H. Moor, and Eric Steinhart. Berlin: Springer (2012)

[488] Dealing with most risks comes under the category of decision theory: finding the right approaches to maximise the probability of the most preferred options. But an intelligent agent can react to decisions in a way the environment cannot, meaning that interactions with AIs are better modelled by the more complicated discipline of game theory.

[489] See Yudkowsky, Eliezer.: Artificial intelligence as a positive and negative factor in global risk. Global catastrophic risks 1 (2008): 303.

[490] See Muehlhauser, Luke, and Nick Bostrom.: Why we need friendly AI. Think: Philosophy for Everyone (2014).

[491] The balance is currently very uneven, with only three small organisations – the Future of Humanity Institute, the Machine Intelligence Research Institute and the Cambridge Centre for Existential Risk – and focused mainly on the risks of AI, along with some private individuals.

[492] See Sandberg, Anders, and Nick Bostrom.: Whole brain emulation: A roadmap. Future of Humanity Institute Technical Report #2008-3, Oxford University (2008).

[493] A dangerous AI would be a very intelligent that could acquire great power in the world, and would have goals that were not compatible with full human survival and flourishing. There are a variety of ways of avoiding this. "Friendly AI" projects focus on the AI's goals directly, and attempt to make these compatible with human survival. The Oracle AI approach attempts to "box" the AI (constrain its abilities to influence the world) in order to prevent it from acquiring power. The reduced impact AI is a novel approach which attempts to construct AIs goals that are not friendly per se, but that motivate the AI to have a very limited impact on the world, thus constraining the potential damage it could do.

[494] There are many different designs for AIs, and disagreements about whether they could be considered moral agents or capable of suffering. At one end of the scale is the theoretical AIXI(tl), which is essentially nothing more than an equation with vast computing power; at the other lie whole brain emulations, copies of human minds implemented inside a computer. Suffering for the first design seems unlikely; suffering for the second seems very possible. Determining whether a specific AI design can suffer will be an important part of figuring out what to do with it; it seems unlikely that we'll have hard and fast rules in advance.

[495] The idea behind uploads, also called whole brain emulations, is to take a human brain, copy the position of its neurones and connections to sufficient precision, and then run the emulation forwards according to the laws of physics and chemistry. It should then behave exactly as a human brain in the real world. See http://www.fhi.ox.ac.uk/brain-emulation-roadmap-report.pdf for more details, which also goes into the requirements and tries to estimate the likelihood off success of such an approach (it depends on certain likely but uncertain assumptions about how the brain works at the small scale; ie that most things below a certain scale can be handled statistically rather than through detailed modelling).

[496] There's two ways there could be diminishing returns to intelligence: first, it might not be possible for an AI to improve its own intelligence strongly. Maybe it could find some ways of better executing its algorithms, and a few other low-hanging fruits, but it's very possible that after doing this, it will find that the remaining intelligence-increase problems are hard, and that it hasn't improved itself sufficiently to make them easy (you could analogise this to dampened resonance - initially the AI can improve its intelligence quite easily, and this gives it more intelligence with which to work, allowing it to improve its intelligence still further; but each time, the effect is less, and it soon plateaus).

The other way there could be diminishing returns to intelligence is if intelligence doesn't translate into power effectively. This is more likely with things like social intelligence: it seems plausible that no entity could convince, say, 99% of Britain to vote for their party, no matter how socially intelligent it was. Scientific and technological intelligence could conceivably be limited by creativity (unlikely), constraints on the speed of making experiments, or just the fact that humans have solved the easy problems already.

[497] See DARPA's briefing, DARPA-SN-13-30: Probabilistic Programming for Advancing Machine Learning (PPAML) (2013).

[498] See for instance Curtis, Jon, Gavin Matthews, and David Baxter.: On the effective use of Cyc in a question answering system. Proc Workshop on Knowledge and Reasoning for Answering Questions. (2005).

[499] See The Rise of Industrial Big Data, GE Intelligent Platforms (2013).

[500] Such as Watson's triumph on "Jeopardy!" (source: Ferrucci, David, et al.: Building Watson: An overview of

the DeepQA project. AI magazine 31.3 (2010): 59-79).

[501] See the Wired report by Steven Levy, How Ray Kurzweil Will Help Google Make the Ultimate AI Brain (2013).

[502] "Soon after [1988] came a period called the 'AI Winter,' in which many companies fell by the wayside as they failed to deliver on extravagant promises." (Source: Stuart, Russell, and Norvig Peter. "Artificial intelligence: a modern approach." Upper Saddle River, New Jersey: Prentice Hall (2003) pp24).

[503] "At its low point, some computer scientists and software engineers avoided the term artificial intelligence for fear of being viewed as wild-eyed dreamers." (Source: New York Times report by John Markov: Behind Artificial Intelligence, a Squadron of Bright Real People (2005)).

[504] See Ferrucci, David, et al.: Building Watson: An overview of the DeepQA project. AI magazine 31.3 (2010): 59-79.

[505] See Guizzo, Erico.: How Google's self-driving car works. IEEE Spectrum Online (2011).

[506] See Kurzweil, Ray.: The Age of Spiritual Machines: How we will live, work and think in the new age of intelligent machines. Orion (1999).

[507] See Sotala, Kaj and Roman V. Yampolskiy.: Responses to Catastrophic AGI Risk: A Survey. Technical report 2013-2. Berkeley, CA: Machine Intelligence Research Institute (2013)

[508] The term AI is now ambiguous, with various "narrow AIs" being produced (such as self-driving cars or stock-trading programmes). An "AGI" returns to the original meaning of AI, that of an artificial being with general intelligence skills. This report will use the term AI interchangeably with AGI, however.

[509] See Armstrong, Stuart, and Kaj Sotala. 2012.: How We're Predicting AI—or Failing To. In Beyond AI: Artificial Dreams, edited by Jan Romportl, Pavel Ircing, Eva Zackova, Michal Polak, Radek Schuster, 52–75

[510] See Yudkowsky, Eliezer.: Levels of Organization in General Intelligence. In Artificial General Intelligence, edited by Ben Goertzel and Cassio Pennachin 389–501 (2007).

[511] See Bostrom, Nick.: The superintelligent will: Motivation and instrumental rationality in advanced artificial agents. Minds and Machines 22.2 (2012): 71-85, and Armstrong, Stuart.:General purpose intelligence: arguing the Orthogonality thesis." Analysis and Metaphysics (2013).

[512] See the Less Wrong summary post Complexity of value for a discussion on this issue.

[513] See Yampolskiy, Roman V.: Leakproofing the Singularity. Journal of Consciousness Studies 19.1-2 (2012): 194-214.

[514] See Armstrong, Stuart, Anders Sandberg, and Nick Bostrom.: Thinking inside the box: Using and controlling an Oracle AI. Minds and Machines (2012).

[515] See Armstrong, Stuart, Anders Sandberg, and Nick Bostrom.: Thinking inside the box: Using and controlling an Oracle AI. Minds and Machines (2012).

[516] See Dewey, Daniel. "Learning what to value." Artificial General Intelligence. Springer Berlin Heidelberg, (2011). 309-314.

[517] See Thomas, Michael SC, and James L. McClelland. "Connectionist models of cognition." The Cambridge handbook of computational psychology (2008): 23-58.

[518] See Yudkowsky, Eliezer.: Artificial intelligence as a positive and negative factor in global risk. Global catastrophic risks 1 (2008): 303, and Omohundro, Steve.: Rational artificial intelligence for the greater good. Singularity Hypotheses. Springer Berlin Heidelberg. (2012) 161-179.

[519] See James Barrat.: Our Final Invention: Artificial Intelligence and the End of the Human Era. (2013).

[520] See Omohundro, Stephen M.: The basic AI drives. Frontiers in Artificial Intelligence and applications 171 (2008): 483.

[521] Directly coding safe behaviour is seen to be an extremely difficult challenge.

[522] See Armstrong, Stuart, Bostrom, Nick, and Shulman, Carl.: Racing to the precipice: a model of artificial intelligence development. Technical Report #2013-1, Future of Humanity Institute, Oxford University (2013).: http://www.fhi.ox.ac.uk/wp-content/uploads/Racing-to-the-precipice-a-model-of-artificial-intelligence-development.pdf

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[660] http://www.un.org/esa/population/publications/worldageing19502050/pdf/90chapteriv.pdf

[661] http://www.un.org/esa/population/publications/worldageing19502050/pdf/90chapteriv.pdf

[662] http://en.wikipedia.org/wiki/Big_data

[663] For some examples of visualisation tools: http://www.creativebloq.com/design-tools/data-visualization-712402

[664] For a discussion about risk and the importance of probability curves of risk, see Kaplan, Stanley and Garrick, John B., On the Quantitative Definition of Risk, Risk Analysis, Vol. I, No. 1, 1981, in which the authors state (pp. 11–27): "We prefer to say that 'risk is probability and consequence.' In the case of a single scenario the probability times consequence viewpoint would equate a low-probability high-damage scenario with a high-probability low-damage scenario – clearly not the same thing at all. In the case of multiple scenarios the probability times consequence view would correspond to saying the risk is the expected value of damage, i.e., the mean of the risk curve. We say it is not the mean of the curve, but the curve itself which is the risk. A single number is not a big enough concept to communicate the idea of risk. It takes a whole curve. Now the truth is that a curve is not a big enough concept either. It takes a whole family of curves to fully communicate the idea of risk."

[665] http://www.ipcc.ch/pdf/supporting-material/uncertainty-guidance-note.pdf

[666] SNRA covers risks such as school shootings, heatwaves and collapses of hydroelectric dams

[667] https://www.msb.se/RibData/Filer/pdf/26561.pdf

[668] http://www.ipcc.ch/pdf/supporting-material/uncertainty-guidance-note.pdf

[669] Richard Possner has described key elements of such a centre in the book Catastrophe: risk and response. Posner, Richard A. Catastrophe: risk and response. Oxford University Press, 2004.

Appendix 1 – Global Challenges Bibliography

The Global Catastrophic Risk Institute (GCRI) published a GCR bibliography compiled in July 2011 by Seth Baum, available at http://gcrinstitute.org/bibliography. This contains 115 entries, emphasising publications surveying the breadth of the risks or discussing other topics of general interest to the study of GCR, with less emphasis on analysis of specific global challenges. It has been updated for this Global Challenges Foundation report and now contains 178 entries.

The reason for focusing on general interest publications is because the literature on specific global challenges is far too voluminous to catalogue. It would include, for example, a significant portion of the literatures on climate change, energy, nuclear weapons, infectious diseases and biodiversity, all topics that receive extensive research attention. Thus the full bibliography compiled by GCRI is only a small portion of the total global challenges literature.

Publications for the full bibliography were identified in several ways. The bibliography began with publications already known to fit the selection criteria. Additional publications were identified by examining the reference lists of the initial publications.

More publications were identified by searching scholarly databases (mainly Web of Science and Google Scholar) and databases of popular literature (mainly Amazon and the New York Public Library) for relevant keywords and for citations of the publications already identified.

Several keywords and phrases were searched for in the databases: “existential catastrophe”; “existential risk”; “global catastrophe”; “global catastrophic risk”; “greatest global challenges”; “human extinction”; “xrisk”; and “infinite risk”. The results of these searches were then screened for relevant publications. Many of the results were not relevant, because these terms are used in other ways. For example, “existential risk” is sometimes used to refer to risks to the existence of businesses, countries or other entities; “human extinction” is used in the study of memory. The publications that use these terms in the same sense as the bibliography were then further screened for publications of general global challenges interest, not for specific global challenges.

The most productive search term for the database searches turned out to be “global catastrophe”. This term produced a relatively large number of hits and relatively few publications on unrelated topics.

Further, the term is used by researchers from a variety of different backgrounds. This makes it a particularly fruitful term for discovering new global challenges research.

One hallmark of the global challenges topic is that it is studied by distinct research communities that have limited interaction with each other. As research communities often develop their own terminology, it can be difficult to discover one community by searching for another’s terms. For example, “existential risk” is used heavily by researchers studying risk from artificial intelligence and other emerging technologies, but it is rarely used by researchers studying environmental risks. Discovering and connecting the disparate corners of the GCR research is an ongoing challenge for the GCR community. Bibliography searches such as these are an important way to meet this challenge.

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Appendix 2 – Workshops

Workshop 1
14 January 2014,
at the Future of Humanity Institute (FHI), University of Oxford:

Participants

Stuart Armstrong, James Martin Research Fellow, FHI, Oxford
Seth Baum, Executive Director of the Global Catastrophic Risk Institute
Nick Beckstead, Research Fellow, FHI, Oxford
Eric Drexler, Academic Visitor, James Martin Research Fellow, FHI, Oxford
Madeleine Enarsson, Transformative Catalyst, 21st Century Frontiers
Seán Ó hÉigeartaigh, James Martin Academic Project Manager, FHI, Oxford and project manager, Cambridge's Centre for Study of Existential Risk, Cambridge
Patrick McSharry, head of Smith School's Catastrophe Risk Financing research area.
Vincent Müller, James Martin Research Fellow, FHI, Oxford
Robert de Neufville, Professional Associate, Global Catastrophic Risk Institute
Toby Ord, James Martin Research Fellow, FHI, Oxford
Dennis Pamlin, Executive Project Manager, Global Challenges Foundation
Jules Peck, Founding Partner, Jericho Chambers; Trustee, New Economics Foundation
Anders Sandberg, James Martin Research Fellow, FHI, Oxford
Andrew Simms, Author, Fellow at the New Economics Foundation and Chief Analyst at Global Witness
Andrew Snyder-Beattie, Academic Project Manager, FHI, Oxford
James Taplan, Principal Sustainability Advisor, Forum for the Future
Raj Thamotheram, CEO, Preventable Surprises

Agenda

09.30 Welcome

09.35-09.50: Round of introductions

09.50-10.10
Introducing the Global Challenges Foundation and the work with the "Global Challenges Report"
What is the background for this work, draft structure of the report and agenda for the day?

10.10-10.40
Global Challenges in society today and global risks
Who cares about and works with the major global challenges that pose an existential threat and who wants to cancel the apocalypse? In short: In what context will the report be received?

10.40-11.40
Major events during 2013 and links to 2014
Discussing the draft list and structure. What is missing, especially with regards to emerging countries? What could happen during 2014 that we think should be reflected in the report?

11.40-12.30
Infinite impacts
How can infinite impacts be defined and presented in ways that make policy makers take them seriously? What models and narratives exist, what coalitions can work with such questions?

12.30-13.30 Lunch

13.30-14.30
Major challenges
Probabilities and impacts, discussions regarding the challenges. Who can provide an estimation of the risk and who can continue to work on these? Are there synergies between them?

14.30-15.30
Emerging challenges
Probabilities and impacts, discussions regarding the challenges. Who can provide an estimation of the risk and who can continue to work on these? Are there synergies between them and between them and today's major challenges?

15.30-16.00
Natural challenges and policy challenges
How to deal with these challenges that are different, especially policy challenges?

16.00-16.30
Next steps and need for funding
Based on the discussion during the day, what are possible next steps? Are there initiatives/work in need of funding? What role could a quarterly Global Challenges/risk report have?

Workshop 2
15 January 2014
at the Munich RE office in London:

Participants

Oliver Bettis, pricing actuary Munich RE and fellow of the Chartered Insurance Institute and the Institute & Faculty of Actuaries.
Madeleine Enarsson, Transformative Catalyst, 21st Century Frontiers
Jennifer Morgan, Founder & Co-Convener, the finance lab
Dennis Pamlin, Executive Project Manager, Global Challenges Foundation
Nick Silver, director of Callund Consulting and founder and director of the Climate Bonds Initiative (CBI)
Liang Yin, Investment Consultant at Towers Watson

Agenda

11.00-11.05
Welcome

11.05-11.15
Round of introductions

11.15-11.30
The Global Challenges Foundation and a risk report

11.30-12.00
Infinite impacts and global challenges.

12.00-12.15
What risks with a possible infinite impact are on the radar screen of actuaries today (comparing the list from Oxford with current actuary work) and how can "Infinite impacts" be addressed?

12.15-12.45
Relations and overview

12.45-13.00
How can infinite impacts be included in mainstream actuary work? How can thought leaders in the actuarial profession begin to include infinite impacts?

13.00-13.30
What should the report include to be relevant for actuaries/financial sector?

13.30-14.00
Possible ways forward

Notes

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12 Risks that threaten human civilisation

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