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Planetary Solvency

- finding our balance with nature.

Climate Change Supplementary Material

University of Exeter

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Planetary Solvency Supplementary Material - Contents

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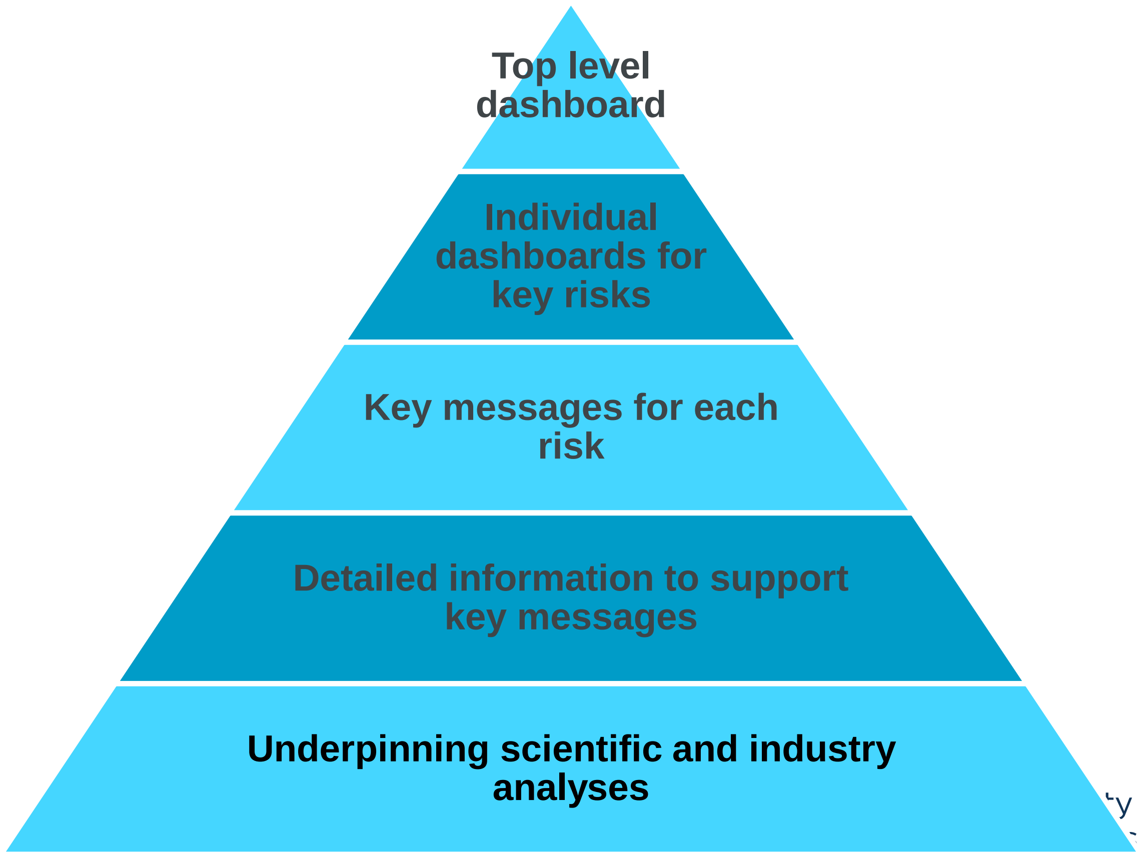
Introduction to supplementary material

- This supplementary material is provided to support the climate change headlines provided in Section 5 of the Planetary Solvency report.
- This is consistent with risk reporting in a large complex organization, where a top-level dashboard is supported by:
  - A more detailed dashboard on each risk
  - Headlines (key messages) relating to each risk
  - More detailed information to support the key messages
  - This detailed information is itself supported by scientific and industry analyses.

  As illustrated in the diagram to the right.
- In this way users of reports can explore the detail that is most pertinent to them and the decisions they are faced with.
- For the illustrative Planetary Solvency output we selected five dimensions: the economy, mortality, climate, nature and society. Additional dimensions could be added as required, for example, space or plastic. Regional or national Planetary Solvency reports could also be produced.

Diagram of risk reporting information flows



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I: Planetary Solvency Framing

Extracts from launch webinar

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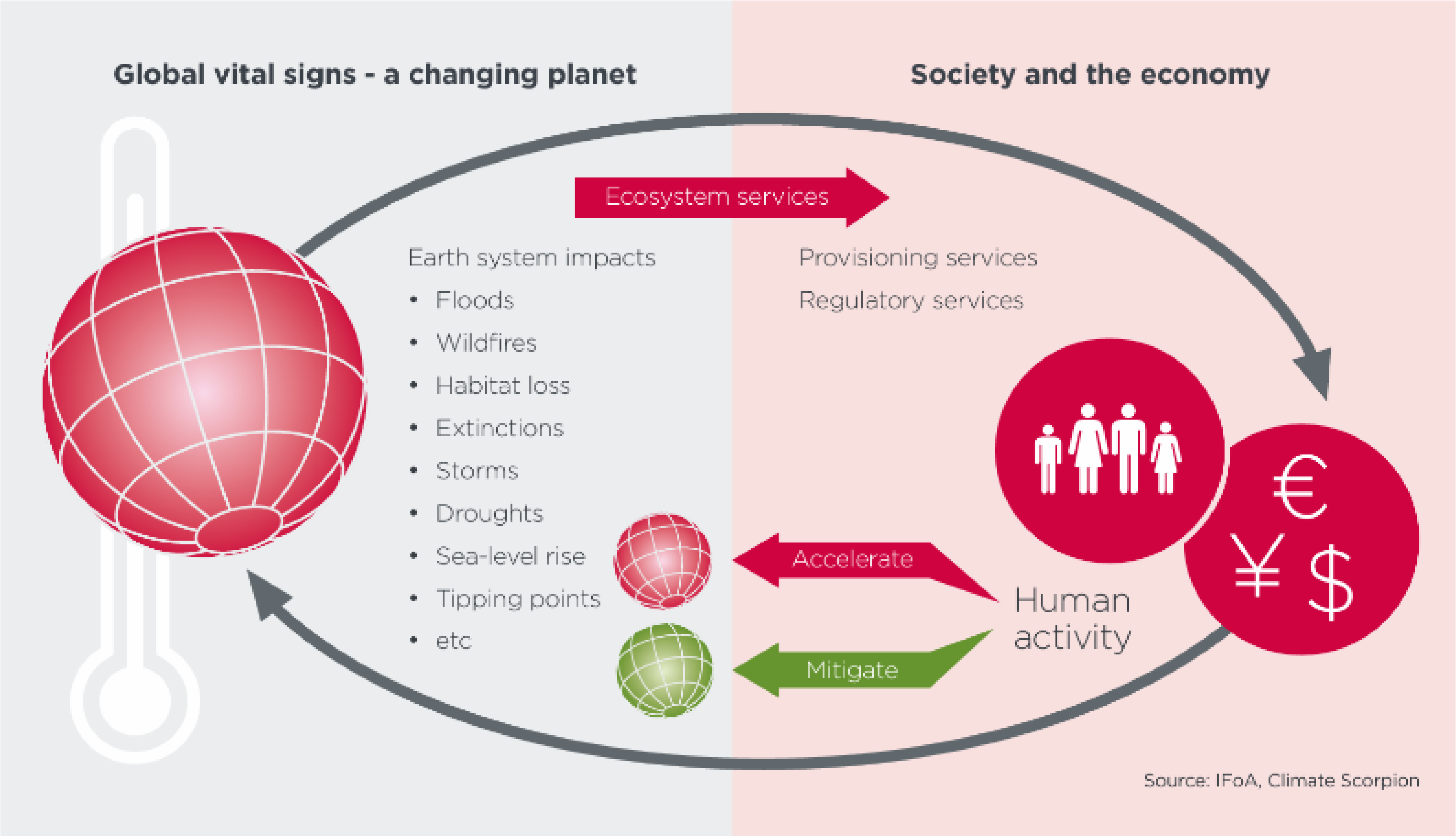
We are part of the Earth system, which we depend on



- **We fundamentally depend** on the Earth system
- **Ecosystem services are not substitutable** and must be protected
- **We need to recognise this** and manage our activity to be within planetary boundaries
- **Urgent policy response** required to maintain Planetary Solvency

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Planetary Solvency is defined as:

"

Managing human activity,

to minimise the risk of societal disruption,

from the loss of critical support services from nature.

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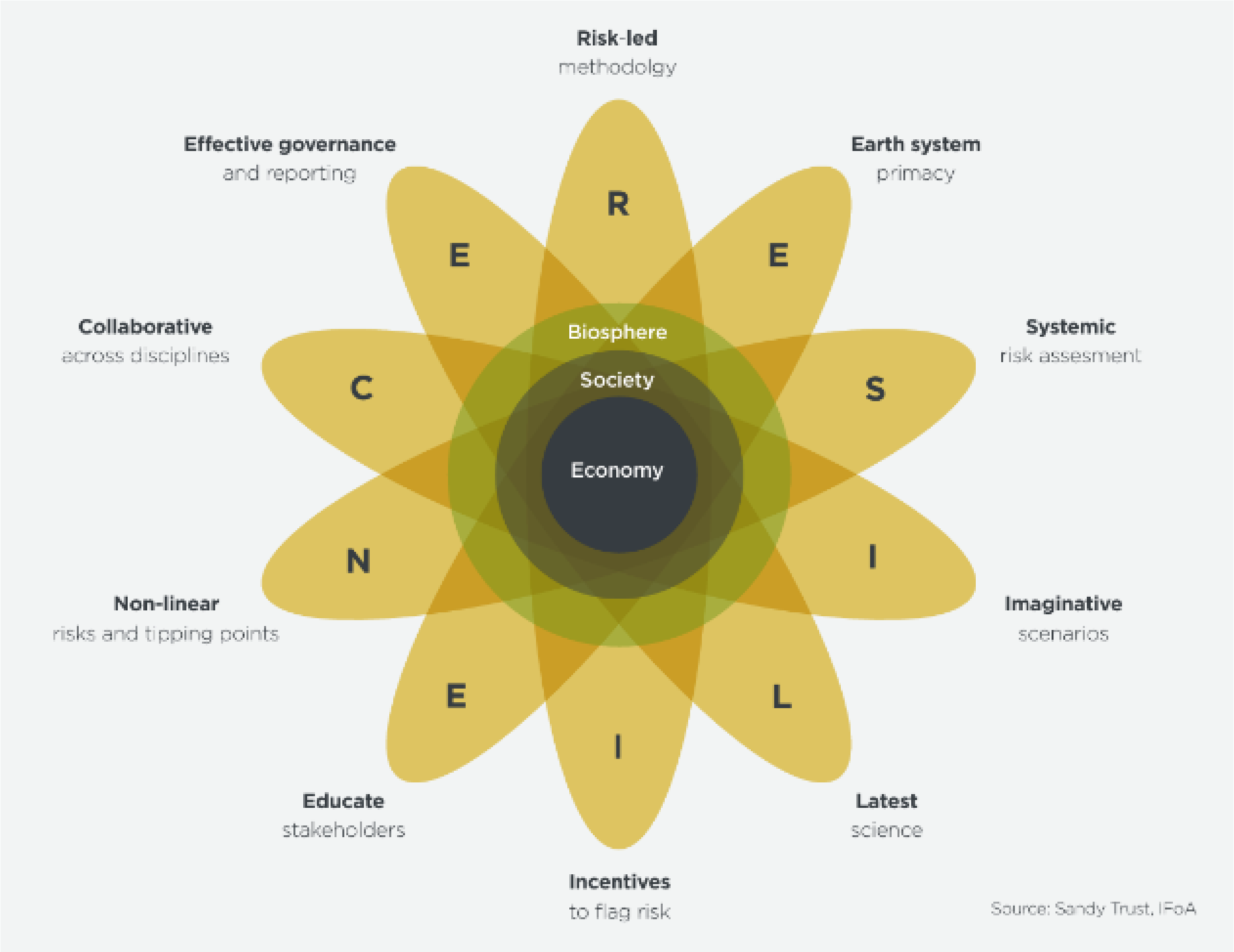
The RESILIENCE principles



- The economy requires a society, which rests in the Earth system
- These systems are now deeply interconnected.
- RESILIENCE principles for realistic and effective risk management
  - Assess risks relative to objectives
  - Identify biggest risks and tail events
  - Use best available information
  - Consider interconnections
  - Non-linearity, range of timeframes

Planetary solvency risk impact and likelihood matrix

RATING	Financial Impact	Non-Financial Impact			
	GDP losses	Human mortality	Climate	Nature	Societal
EXTREME	≥50%	≥50% > 4 billion deaths	3C or more by 2050 Multiple climate tipping points triggered, tipping cascade.	Breakdown of several critical ecosystem services and Earth systems. High level of extinction of higher order life on Earth.	Significant socio-political fragmentation worldwide and/or state failure with rapid, enduring, and significant loss of capital, and systems identity. Frequent large scale mortality events.
CATASTROPHIC	≥25%	≥25% >2 billion deaths	2C or more by 2050 High number of climate tipping points triggered, partial tipping cascade.	Breakdown of some critical ecosystem services and Earth systems. Major extinction events in multiple geographies. Ocean circulation severely impacted.	Severe socio-political fragmentation in many regions, low lying regions lost. Heat and water stress drive involuntary mass migration of billions. Catastrophic mortality events from disease, nutrition, thirst and conflict.
DECIMATION	≥10% >$10 trillion annual losses	≥10% > 800 million deaths	Global warming limited to 2C by 2050 Several climate tipping points triggered.	Severe reduction in several critical ecosystem services. Major extinction events in some geographies. Frequent global food and water crises.	Severe socio-political fragmentation in regions exposed to climate and/or nature impacts. Failure of vulnerable states and mass mortality events in impacted areas.
SEVERE	≥5% >$5 trillion annual losses	≥5% > 400 million deaths	Global warming limited to 1.5C by 2050 following overshoot Some proximate climate tipping points triggered	Some impacts to critical ecosystem services. Ongoing species extinction. Regular global food and water crises.	Some socio-political fragmentation in most vulnerable states, where adaptation has been limited. Fragile states exposed to climate risks see mass migration and mortality events from heat, water stress and weather events.
LIMITED	≥1% >$1 trillion annual losses	≥1% > 80 million deaths	Global warming below 1.5C by 2050, with limited overshoot Climate tipping points largely avoided	Mass extinction avoided and ecosystem services largely functional. Occasional global food crisis and widespread water crises.	Ongoing significant climate impacts with many hundreds of billion dollar + loss events annually and associated mortality and socio-political stress.

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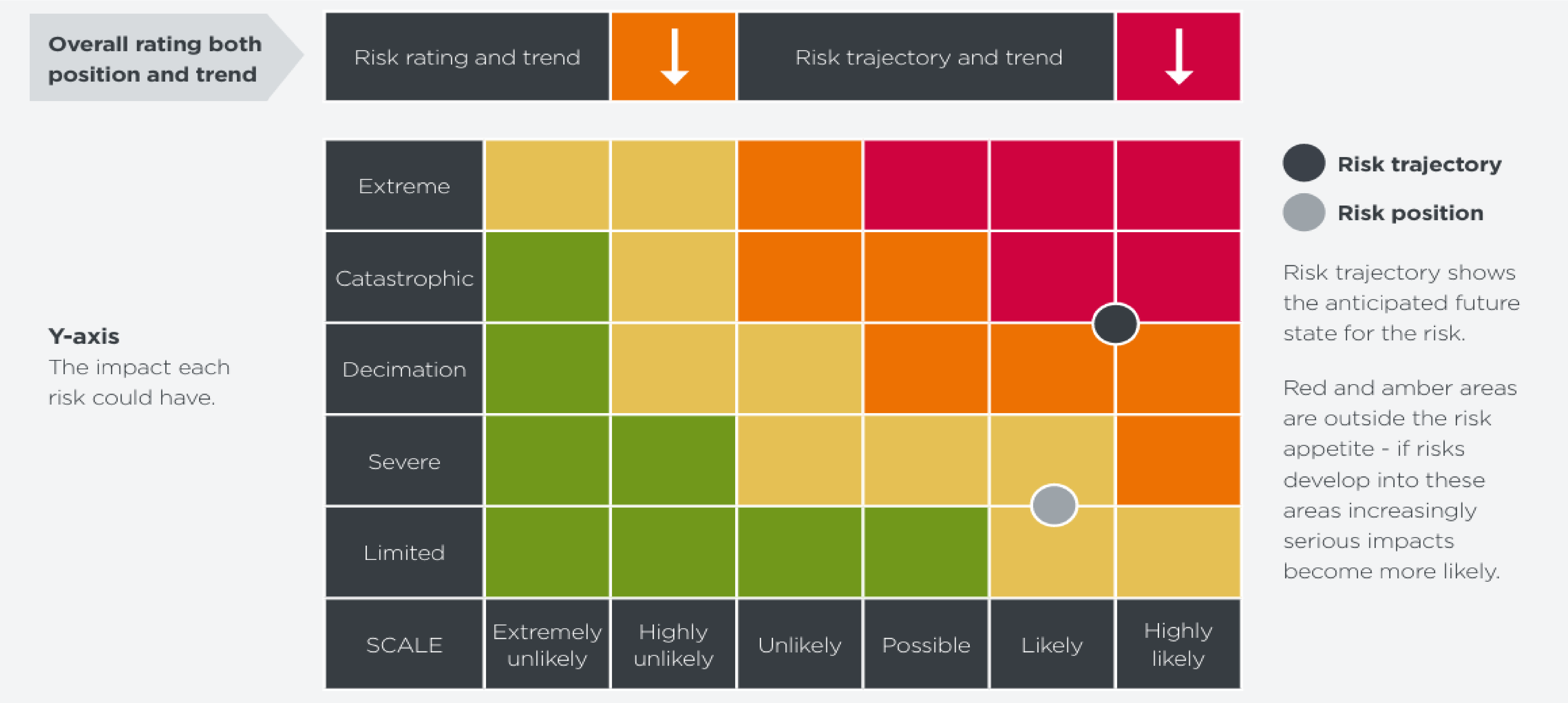
LIKELIHOOD The likelihood of the risk occurring over a certain timeframe	EXTREMELY UNLIKELY	HIGHLY UNLIKELY	UNLIKELY	POSSIBLE	LIKELY	HIGHLY LIKELY
	<1%	1-10%	10-40%	40-60%	60-90%	≥90%

Risk dashboard plotting risk position and trajectory



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II: Illustrative output

Planetary Solvency

Top Level Dashboards

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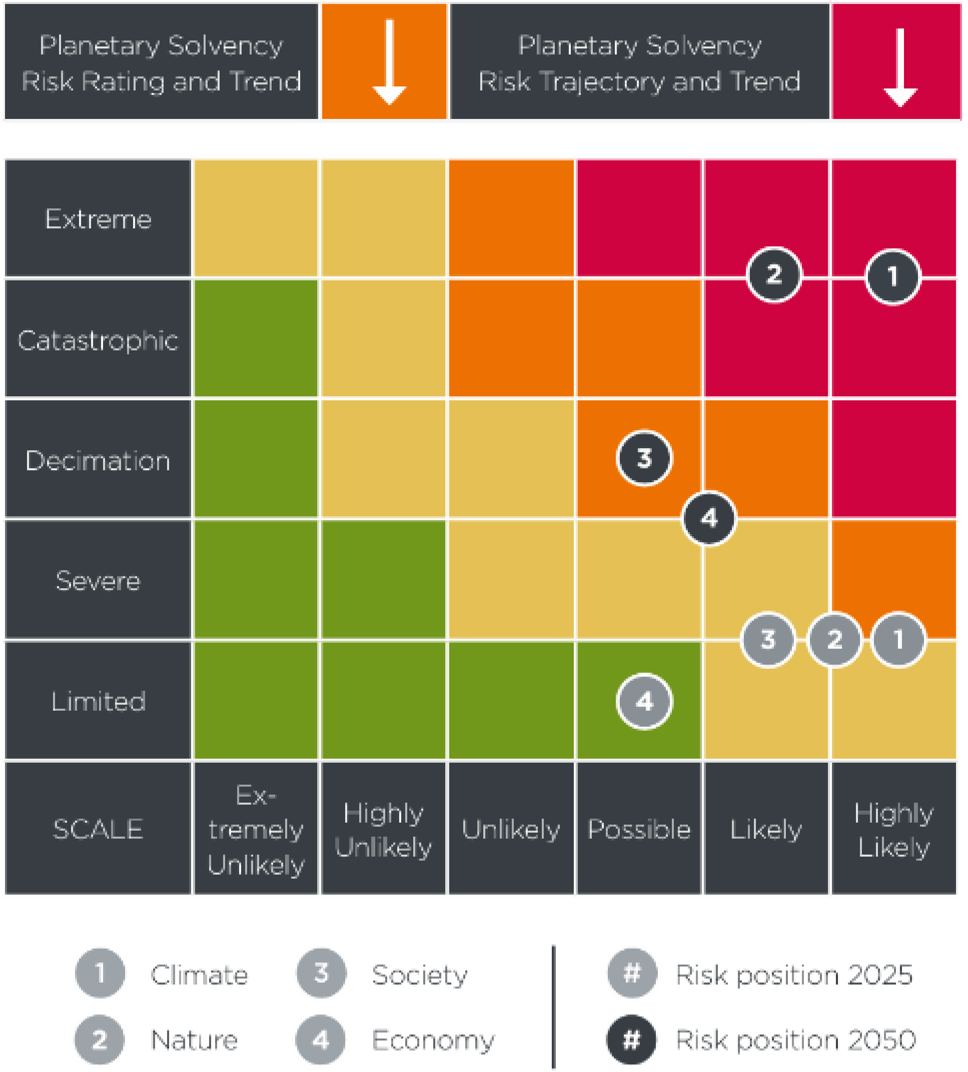
Planetary Solvency Top Level Dashboard – 2025

Planetary Solvency risk position:

- Significant increase in 2025 risk position, with overall position now outside risk appetite.
- Global climate impacts **Severe,** Nature impacts anticipated **Severe** imminently.
- Societal impacts **Limited**, trending to **Severe**.
- Economic and Mortality impacts **Limited**.

Planetary Solvency risk trajectory:

- Risk trajectory pushes all risks further out of appetite soon, with increased breaches of risk tolerances Likely.
- Immediate policy action required to mitigate risks of **Catastrophic** level or greater impacts before 2050.
- Cascading and interconnecting nature of risks requires systemic approach and solution.



1. Climate Risk Dashboard – Global – 2025

Paris Agreement goals will not be met without immediate policy action, risking ruin	Risk Rating and Trend	2025	2050
		AMBER ↓	RED ↓

a) Risk position: AMBER

Impact ***Severe*** in 2024 with globally increased $billion+ loss events and 10k+ mortality events. Now >1.5C (12 mth average) implying overshoot of Paris goals. Ongoing increase of emissions and GHG levels, continued fossil fuel investment. Transition is accelerating.

b) Risk trajectory: RED

Tipping points increase risk exponentially past 1.5C. Emissions and GHG levels imply >2C by 2050. Highly likely ***Catastrophic*** warming levels experienced pre 2050 with ***Extreme*** warming Possible. Policy support required to radically accelerate transition, reduce emissions and leverage natural solutions..

PHYSICAL CLIMATE RISK

- Warming accelerated in 2023, above 1.5°C on 12 mth average, overshoot.
- GHGs + emissions also breaking records, more warming in pipeline.
- Climate impacts increasingly severe globally: fire, flood, heat, drought.
- Nature an undervalued ally that continues to be degraded.

ENERGY TRANSITION

- Energy transition accelerating supported by rapid scaling of transition finance.
- $1 trillion investment in fossil fuels and an all time record for coal investment.
- GDP requires energy, implying more fossil fuel use if renewables absent.
- Energy security and geo-political implications if transition is executed.

RISK & UNCERTAINTY

- Tipping point risk increases >1.5C and several tipping points now triggered.
- Climate sensitivity, Earth may be much more sensitive to GHGs than we think.
- Additional factors driving accelerated warming - aerosol cooling, loss of albedo
- Climate models understate risk, miss non-linear risk impacts and cascading risks.

POLICY ACTION REQUIRED TO BEND RISK TRAJECTORY TO AMBER

1. Implement realistic risk assessment to complement science and communicate risk position and trajectory clearly to policymakers.
2. Prepare for faster than expected warming and higher sensitivity. Revisit carbon budgets, decarbonisation pathways and temp ratings.
3. Adaptation required for increasingly severe and unprecedented risk environment, link resilience to national security agenda.
4. Policy support to accelerate S-curves of energy transition and reduce emissions. Consider nuclear and other alternatives as key mitigants.
5. Incorporate nature and justice into national and corporate transition plan requirements, with supporting education on these topics.

2. Nature Risk Dashboard – Global – 2025

Food, water and health shocks likely as ecosystem services disrupted due to nature loss	Risk Rating and Trend	2025	2050
		↓	↓

a) Risk position: AMBER

2024 impacts trending to ***Severe***. Water and food system stress increasing. Ongoing degradation of nature assets, multiple planetary boundaries breached, high extinction rates, multiple ecosystem threats and major ecoservices at risk. Global agreement to mitigate biodiversity loss but limited progress on implementation.

b) Risk trajectory: RED

Extractive economy drives increasing risk of multiple ecosystem and related ecoservice failures, exacerbated by climate, with ***Catastrophic*** risks likely and ***Extreme*** risks possible pre-2050. Policy support required to mitigate risks and global governance over global commons required, linked to and supporting climate policies.

PHYSICAL NATURE RISK

- Unprecedented rates of biodiversity loss and ecosystem degradation, drive risks and accelerate climate change.
- Increasingly disruptive impacts on food and water security likely.
- Reduced resilience to natural disasters.
- Human health impacts include zoonotic diseases and reduced health benefits.

NATURE POSITIVE

- Economy drives loss through land-use change, resource exploitation, climate change and ongoing pollution.
- Global agreement and some bright spots – nature can bounce back quickly.
- Need for systemic co-ordinated policy response to achieve 30*30 goals.
- Nature based solutions critical for climate.

RISK & UNCERTAINTY

- Ecosystem collapse can occur quickly due to ecosystem tipping points.
- Lack of forward looking risk indicators around critical ecosystem services.
- Unknown vulnerabilities and resilience of food and water networks.
- Uncertainty around risk interconnectivity, cascades and unprecedented events.

POLICY ACTION REQUIRED TO BEND RISK TRAJECTORY TO AMBER

1. Implement realistic risk assessment to complement science and communicate risk position and trajectory clearly to policymakers.
2. Prepare for food and water system disruption due to nature loss, assess vulnerabilities and take pro-active action to build resilience.
3. Systemic policy response required to protect and restore ecosystems, strengthen regulation and address drivers of nature loss.
4. Consider how to evolve economic system to measure, report, manage and incentivise a nature positive future.
5. Broad based education from top and bottom to build awareness of our reliance on Earth System and risks of ongoing degradation.

3. Societal Risk Dashboard – Global – 2025

	Risk Rating and Trend	2025	2050
Severe and escalating societal disruption threatens future peace and prosperity		↓	↓

a) *Risk position:* YELLOW

Regionally varied ***Limited*** to ***Severe*** impacts in 2024, occasionally ***Decimation*** in fragile states vulnerable to climate and nature impacts. Over 300 million need humanitarian assistance. Several areas of high geopolitical tension, multiple active conflicts with risk of contagion and a trend of increasing economic protectionism..

b) *Risk trajectory:* AMBER

Water, food and heat stress, zoonotic diseases increase migration and conflict. Possible to Likely risk of ***Severe*** to ***Decimation*** level societal impacts, with severe socio-political fragmentation and conflict in more regions. Reduced aid budgets negatively impact health and societal response to >1 billion needing assistance. Geopolitical tensions (economic, demographic, geographic, energy, digital and space), misinformation and inequality complicate response and increase vulnerability.

GEOPOLITICS

- Conflicts and military expenditure increasing, numerous conflict zones.
- Increasingly polarised world, waning appetite for multilateralism.
- Tech driving division (social media / misinformation), impact of AI, cyber war.
- Economic growth forecasts decreasing with potential for headwinds.

HUMAN IMPACT

- > 300 million requiring humanitarian assistance globally, aid budget reducing.
- Billions impacted by conflict, water, food and heat stress and extreme events.
- Range of negative health and wellbeing impacts in affected regions.
- Inequality driving political instability and inconsistent policy responses over time.

RISK & UNCERTAINTY

- Impact of ageing populations and reduced fertility on economies and geopolitics.
- Whether disruptive physical risks drive co-operation or conflict/protectionism.
- Scale and pace of involuntary mass migration due to conflict/uninhabitability.
- Response – science informed resilience build vs denialism and reacting to events.

POLICY ACTION REQUIRED TO BEND RISK TRAJECTORY TO YELLOW

1. Implement realistic risk assessment to complement science and communicate risk position and trajectory clearly to policymakers.
2. Recognise need for science and risk informed co-ordinated adaptation activity to guide response and build resilience to anticipated events.
3. Develop solutions for collaboration on material Planetary Solvency risks, recognising need to mitigate human and economic impacts.
4. Forward planning for unprecedented migratory flows required, including dynamics for ageing nations to become migrant seeking.
5. Evolution of national goals to focus on improving human outcomes as well as economic goals.

4. Economic Risk Dashboard – Global – 2025

Unrecognised societal and environmental risks may lead to losses in productive capacity	Risk Rating and Trend	2025	2050
		↓ (green)	↓ (amber)

a) *Risk position:* **GREEN**

Limited economic impacts in 2024, although scale of climate events and subsequent losses continues to trend upwards towards 1% of GDP. Awareness of insurance withdrawal rising with economic implications. Climate litigation increasing. Energy and materials use grow in line with economy with some scarcities emerging.

b) *Risk trajectory:* **AMBER**

Latest estimates of climate impacts forecast an expected 19% GDP impact by 2050 but still exclude many risks, including tipping points and nature risks. ***Decimation*** or ***Catastrophic*** level economic impacts of >25% GDP loss by 2050 now Possible due to high range of uncertainty and impact of interconnected risk drivers. Economic inputs of capital, labour, raw materials and energy may all be impacted significantly by complex basket of interconnected risk events.

GLOBAL ECONOMY

- Forecasts of steady global growth (3.3%), but below pre-pandemic levels.
- China and US forecast to provide steady growth in short term.
- Developing countries headwinds include debt costs, investment and high costs.
- Impact of inflation, economic policies and tariffs.

HEADWINDS

- Dominant economic model blind to climate and nature risks.
- Policy measures currently inadequate to price and address externalities.
- Inflation may continue to hit end consumer demand in multiple markets.
- Supply of economic inputs impacted by scarcity and complex risk events.

RISK & UNCERTAINTY

- Extent to which new technologies, including space, grow economy.
- Pace and scale of energy transition, with potential for cheaper energy in the future.
- Extent of climate, nature and societal driven disruption to economic activity.
- Ongoing evolution of geopolitics, protectionism vs global cooperation.

POLICY ACTION REQUIRED TO BEND RISK TRAJECTORY TO AMBER

1. Implement realistic risk assessment to complement science and communicate risk position and trajectory clearly to policymakers.
2. Refine dominant economic model to recognise criticality of Earth system for ongoing provision of baseline economic inputs.
3. Develop concise set of information for policymakers on refined economic model to inform policy decisions.
4. Intentional policy choices to reduce inequality and manage Planetary Solvency through regulation and incentives.
5. Consider how to develop international financial mechanisms to facilitate growth in developing economies.

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III: Climate Risk Dashboard

Supplementary material

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Climate change headlines – acceleration, uncertainty, opportunity and risk

1 **12-month average temperatures have now exceeded 1.5°C above pre-industrial level, the lower temperature goal of Paris.**
Global warming has also accelerated, climate scientists have yet to explain it fully.

2 **This warming trend is likely to accelerate further as emissions continue at high levels.**
Catastrophic levels of warming, >2C by 2050 are likely unless immediate action is taken.

3 **Current 'net zero' carbon budgets need revising as they will not limit warming to 1.5°C.**
The Earth may be much more sensitive to greenhouse gases than the central assumption used in carbon budgets, implying much more warming than expected.

4 **Climate change is driving increasingly severe impacts: fires, floods, heat and droughts**.
This is a human security issue with food, water and heat stresses impacting populations. If unchecked, mass mortality and/or migration and/or severe economic shocks are likely.

5 **Paris Goals risk triggering multiple climate tipping points as we breach 1.5°C**.
These include irreversible collapse of ice sheets, abrupt permafrost thaw, Amazon die back and halting major ocean current circulation. There is a point of no return beyond which it may be impossible to stabilize the climate.

6 **Policy action required to reduce emissions, accelerate energy transition, adapt and mitigate risk**.
The energy transition is accelerating with economic solutions now available. The pace can be increased or decreased by policy incentives.

Climate infographic – acceleration past 1.5C, risks, tipping points and high emissions.

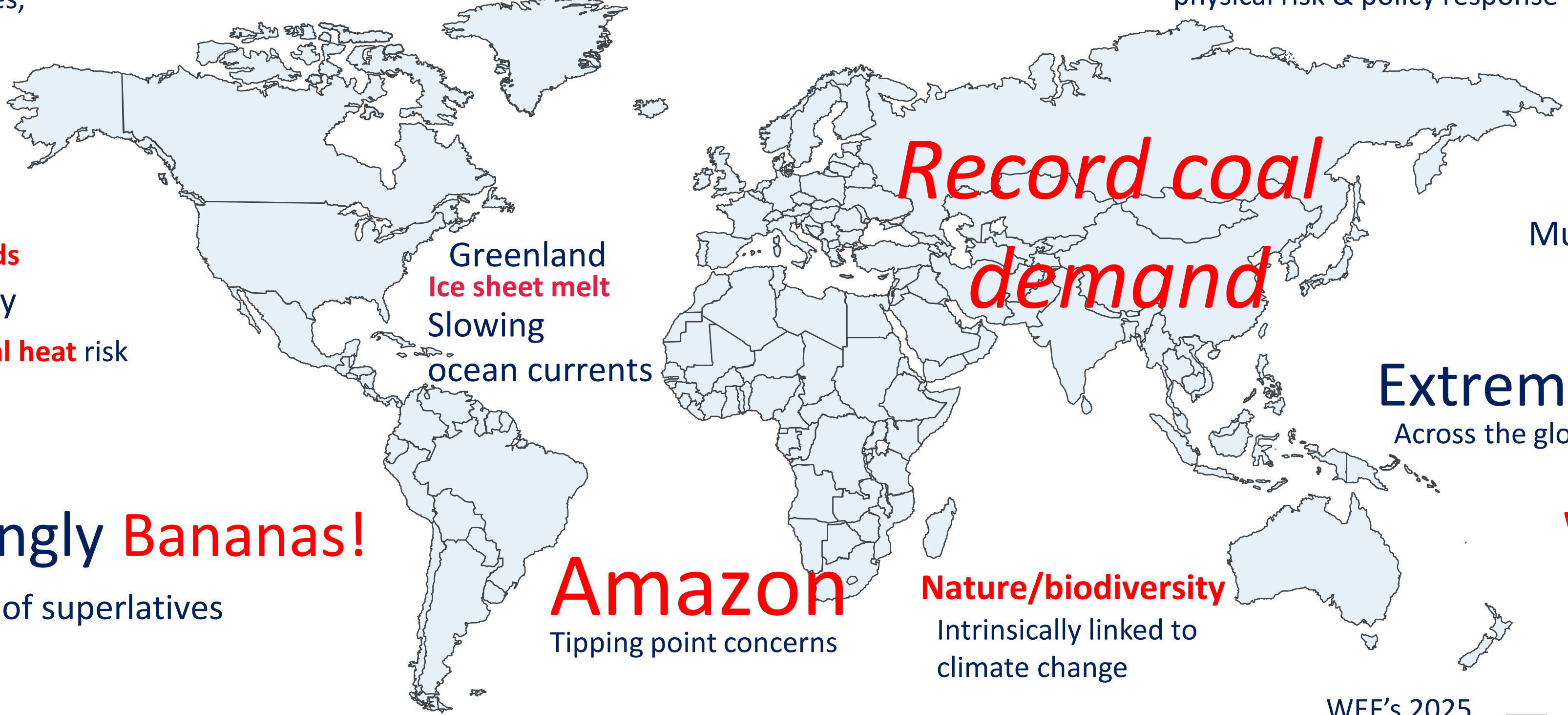
>$300 billion
Annual insured losses, ratcheting up

Arctic sea ice loss 70 years ahead of models
Driving weather extremes globally

Temperatures
rise faster than expected – driving physical risk & policy response

1.5°C in 2024
Risks triggering tipping points

Emissions in line with
Hot house world



Record coal demand

Temperature records
Tumble Globally
Increasing **lethal heat** risk

Greenland
Ice sheet melt
Slowing ocean currents

Multiple **breadbasket failure**
- likelihood increasing – 700m hungry

Extreme weather
Across the globe

Gobsmackingly Bananas!
Scientists run out of superlatives

Amazon
Tipping point concerns

Nature/biodiversity
Intrinsically linked to climate change

Water stress increases
In multiple locations threatening disruption

West Antarctic icesheet
collapse

Tense **geopolitics**
Complicate co-operation and drive risk

WEF's 2025 "The Global Risk Report": **Top Risks**

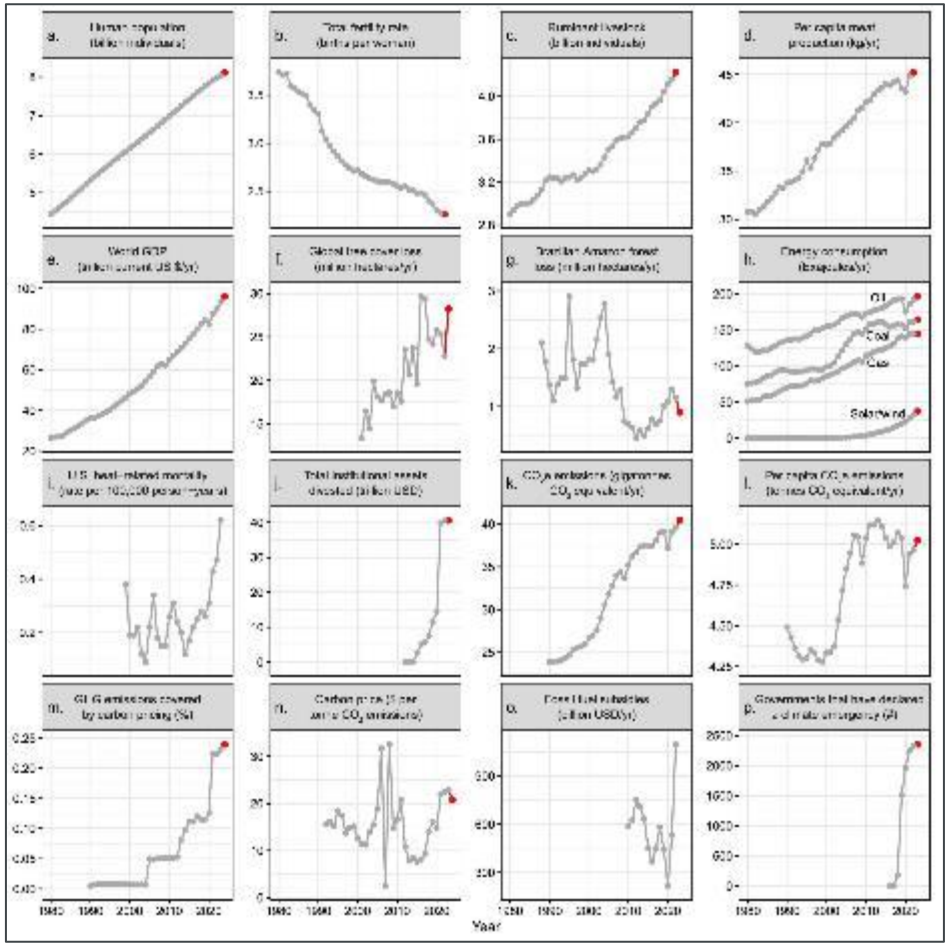
2 year horizon: **Misinformation, Extreme weather, Conflict**

10 year horizon: **Extreme weather, biodiversity loss, Earth systems**

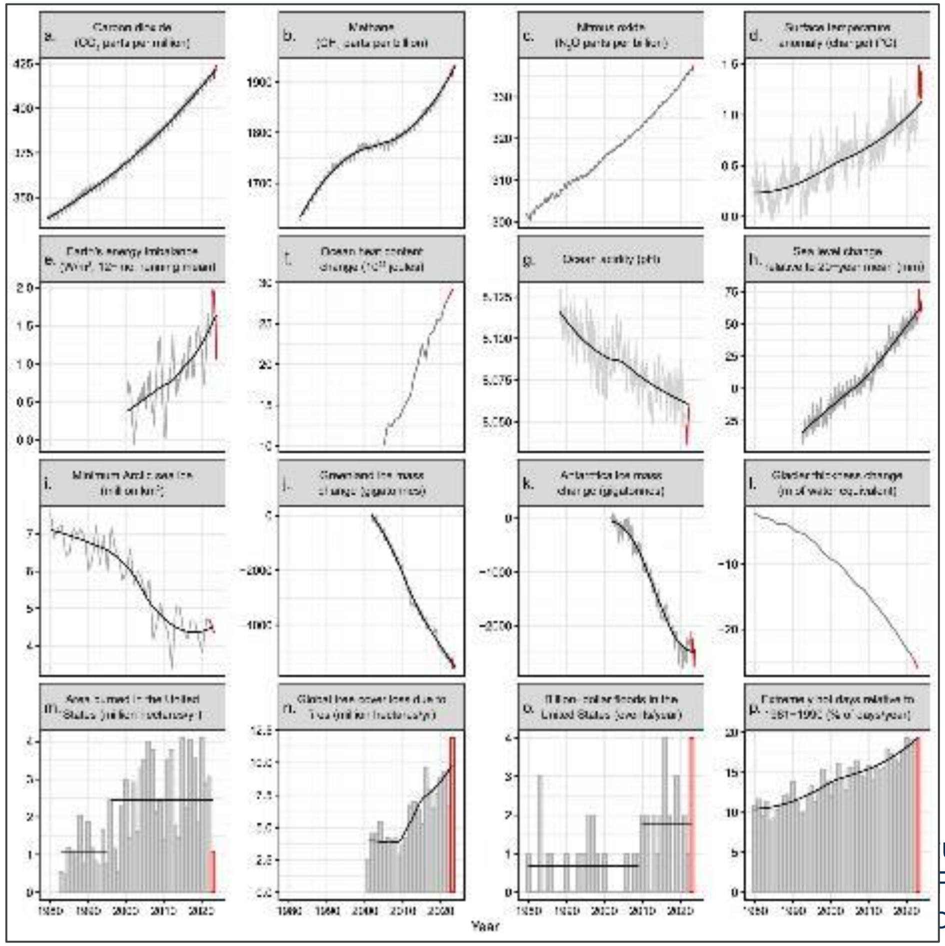
Climate chance key risk indicators I (indicative)

Each dimension of Planetary Solvency would be supported by a set of Key Risk Indicators (KRIs). We show here illustrative KRIs from recent scientific papers referenced in the report. The indicators below are taken from Ripple et al's annual State of the Climate report.

Timeseries of climate-related human activities



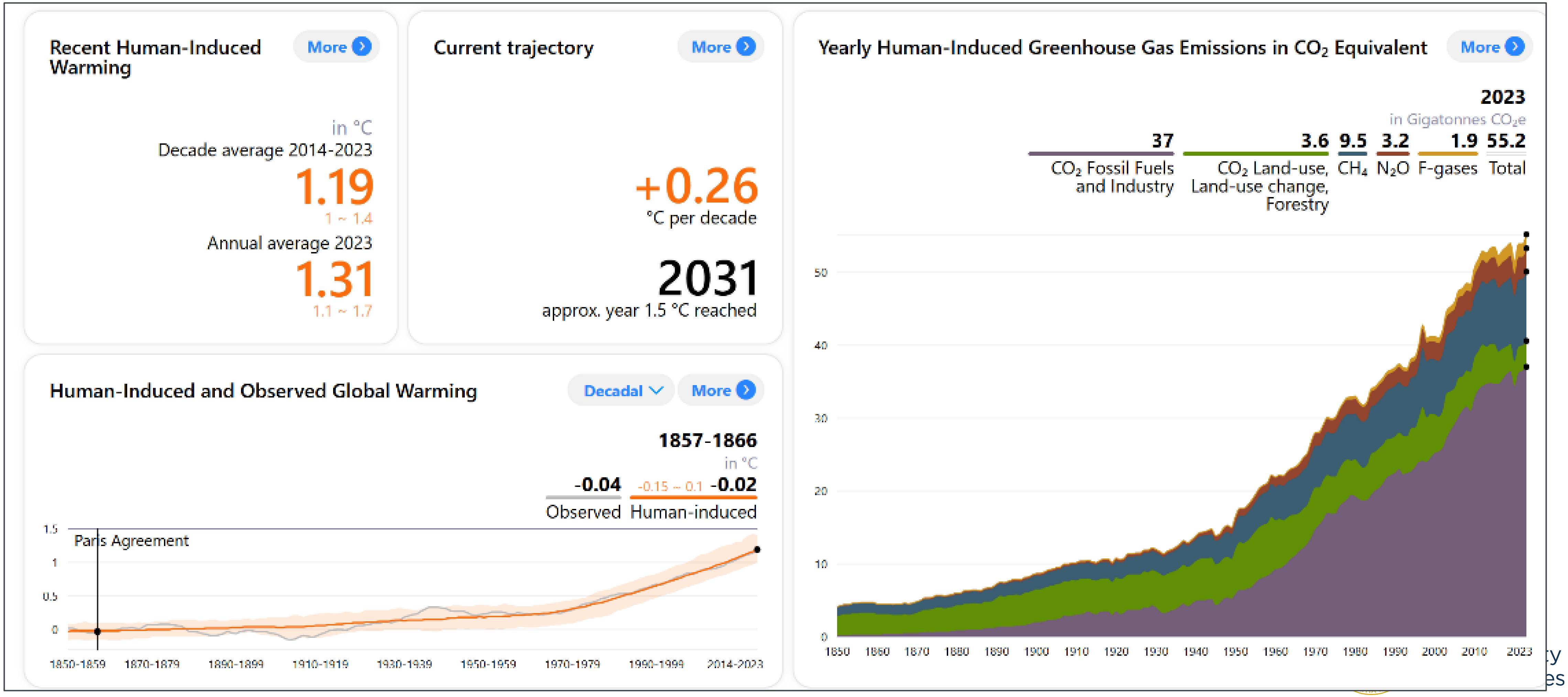
Timeseries of climate-related responses



Source: https://doi.org/10.1093/biosci/biae087

Climate chance key risk indicators II (indicative)

An alternative presentation of climate KRIs is provided by the Indicators of Global Climate Change initiative which provides annual updates inbetween IPCC reporting on a range of climate metrics.



Source: Indicators of Global Climate Change 2023, IGCC Initiative Dashboard and Data: ClimateChangeTracker.org

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1. 12-month average temperatures have now exceeded 1.5°C above pre-industrial level, the lower temperature goal of Paris. Global warming has also accelerated, climate scientists have yet to explain it fully.

- 1A: Summary - Warming accelerated in 2023, passing 1.5C.
- 1B: The rate of global warming accelerated in 2023 and may not be temporary.
- 1C: Record high temperatures are occurring continuously across the globe.

1A: 12 month average temperatures have exceeded 1.5°C above pre-industrial level.

Summary

- Global warming has accelerated, with average temperatures remaining over 1.5°C above pre-industrial temperature. The decadal rate of warming has increased to 0.26°C per decade. It is not yet known whether this recent increase is a temporary fluctuation or permanent shift. Climate scientists have yet to explain it fully.

- Global averages hide local extremes. Record high temperatures are occurring continuously across the globe, with multiple locations now experiencing 40°C to 50°C peaks. Polar regions are experiencing temperatures 30°C to 40°C higher than normal.

- There is a lag between greenhouse gas levels rising and temperatures increasing. We have not yet experienced the full extent of warming caused by current greenhouse gas levels.

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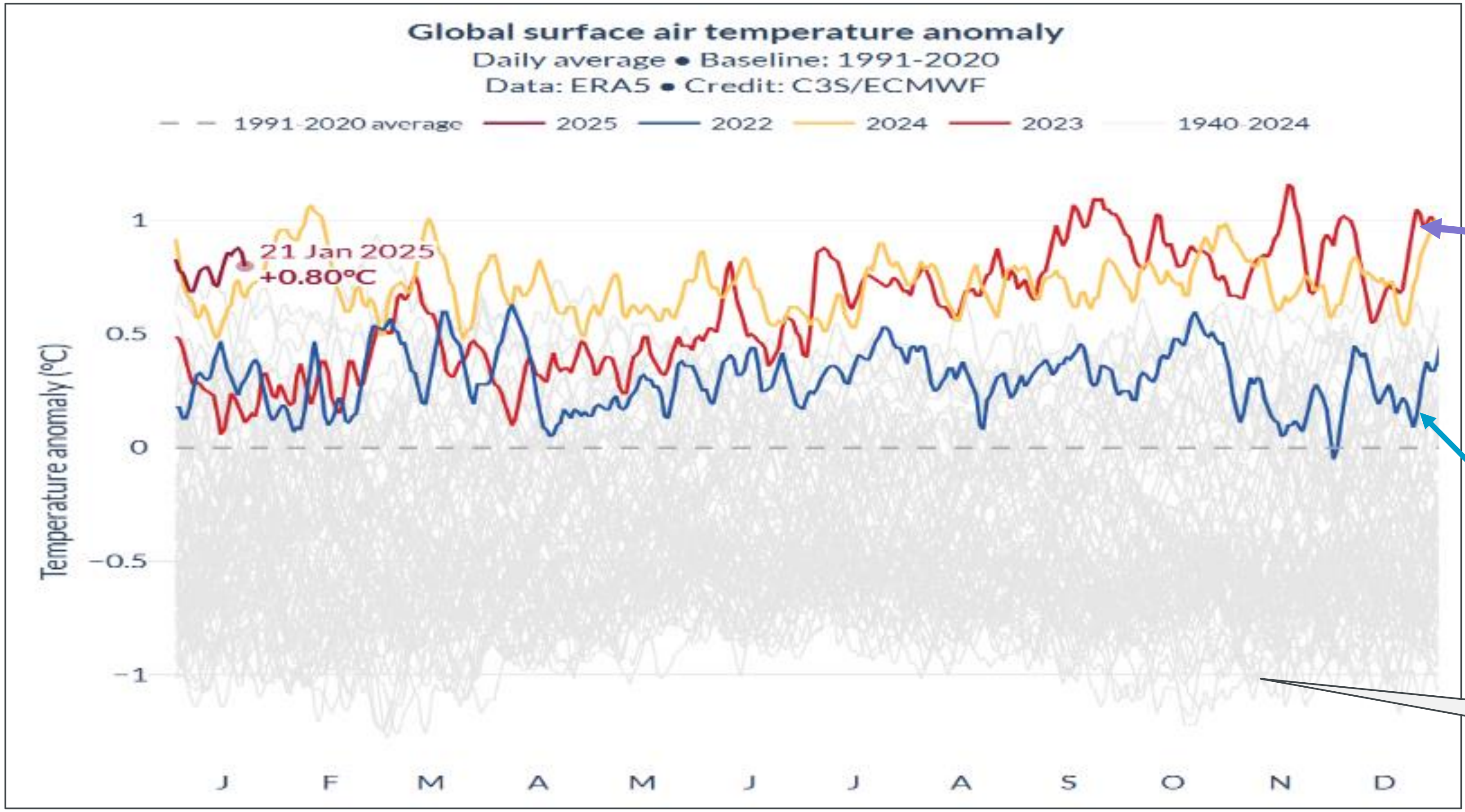
1B: The rate of global warming accelerated in 2023 and may not be temporary.

The last 2 years have consistently set temperature records for hottest month. Sea surface temperatures have also set consistent records for over a year.

The graph below shows a plot of monthly annual air surface temperature anomalies over time, from the 1940s to the present day from the EU's Copernicus programme, that monitors global climate data.



2023 temperatures are shown by the red line. What is striking is the jump up in temperature over the 2nd half of 2023, with temperatures near the 1.75°C mark (above pre-indusrial).

This elevated temperature continued throughout 2024 and early 2025. Scientists are unsure why there was such a striking increase in heat. There may be several factors including the reduction in aerosol cooling caused by changes to shipping regulations that removed sulphur from shipping fuel – an inadvertent geoengineering experiment.

2022, the dark blue line, was similar to although lower than he previous hottest year on record 2016. A significant factor in 2016 was the impact of the El Nino effect, which is temporary (as observed in the temperature reduction in H2 2016).

The grey lines show the decades after WWII when globally temperatures were around 1°C cooler than today.

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Source: Copernicus Pulse

1C: Record high temperatures are occurring continuously across the globe.

While global average temperatures have risen more than expected in recent years, local extremes have consistently exceeded model predictions, surprising scientists, with heat spikes in excess of 4 standard deviations.

Temperature extremes since 2020

- At least 22 countries had recorded maximum temperatures of 50C or more by July 2023.
- In 2022, temperatures in the UK reached 40.3°C, 1.6°C above the previous record.
- In 2023, the national record in China increased by 1.9°C as temperatures hit 52.2°C.
- In Canada, temperature records were broken by 4.6°C, reaching 49.6°C in Lytton, British Columbia
- In East Antarctica, in 2022, the most extreme heatwave recorded anywhere in the world saw temperatures 38.5°C above the local average.

Global averages hide local extremes – selected national temperature records

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Source: Statista, Carbon Brief

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2. This warming trend is likely to accelerate further as emissions continue at high levels.

Catastrophic levels of warming, >2C by 2050 are likely unless immediate action is taken.

- 2A: This warming trend is likely to accelerate further as emissions continue
- 2B: Emissions and energy use continue to rise, which will drive further warming.
- 2C: 2023 – a record year for coal demand…and greenhouse gases.
- 2D: A range of factors may accelerate warming further
- 2E: Catastrophic levels of warming, >2°C by 2050, are likely unless immediate action is taken

2A: This warming trend is likely to accelerate further as emissions continue at high levels.

Summary

- *Catastrophic* levels of warming, >2°C by 2050, are likely unless immediate action is taken. This trajectory will breach the *solvency limits* of the Paris Agreement.

- Coal demand hit record levels in 2023. Consequently, greenhouse gases are also at record high levels and increasing, driving further warming.

- Degradation of natural carbon sinks (e.g. deforestation, over-fishing, pollution) means the natural world is starting to absorb less carbon, which will accelerate warming.

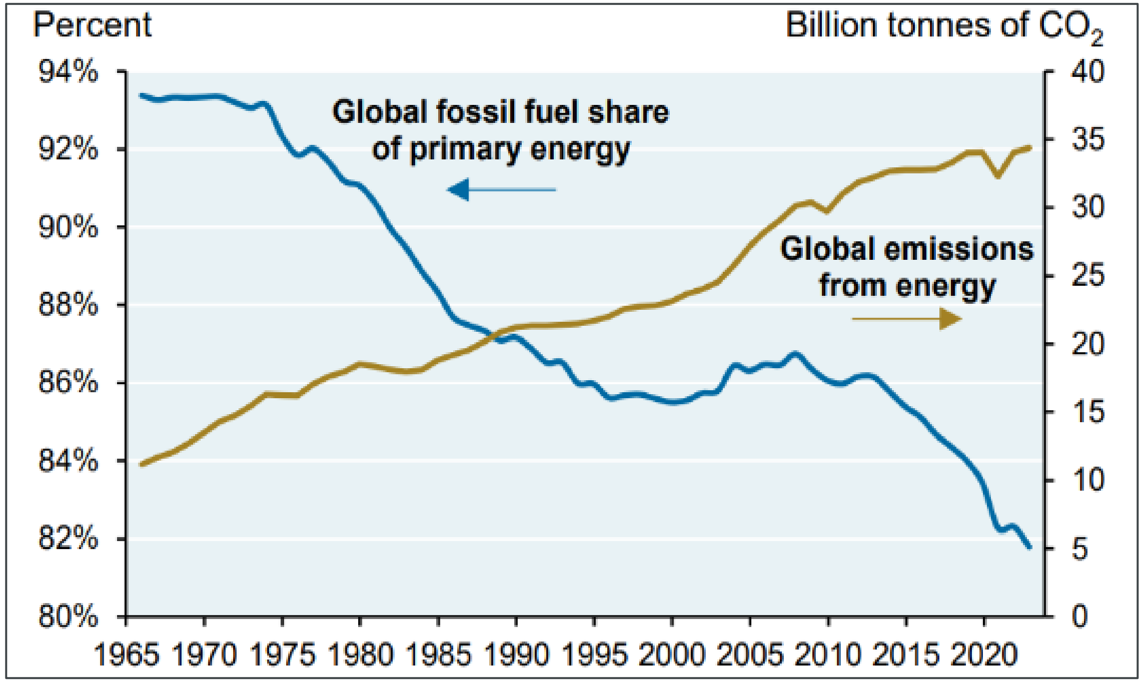
- Other factors acting to accelerate warming include forest fires releasing carbon, ice melt reducing reflectivity, reduction of ocean heat uptake and loss of aerosol cooling.

2B: Emissions and energy use continue to rise, which will drive further warming.

The fossil fuel share of global energy use is falling at c.0.4% per year as the renewable transition progresses, which is similar to the pace of decarbonization that occurred from 1973 to 1988 during the nuclear buildout.

Global CO2 emissions have increased as energy consumption keeps rising; what's falling is the share of primary energy from fossil fuels, not their level.

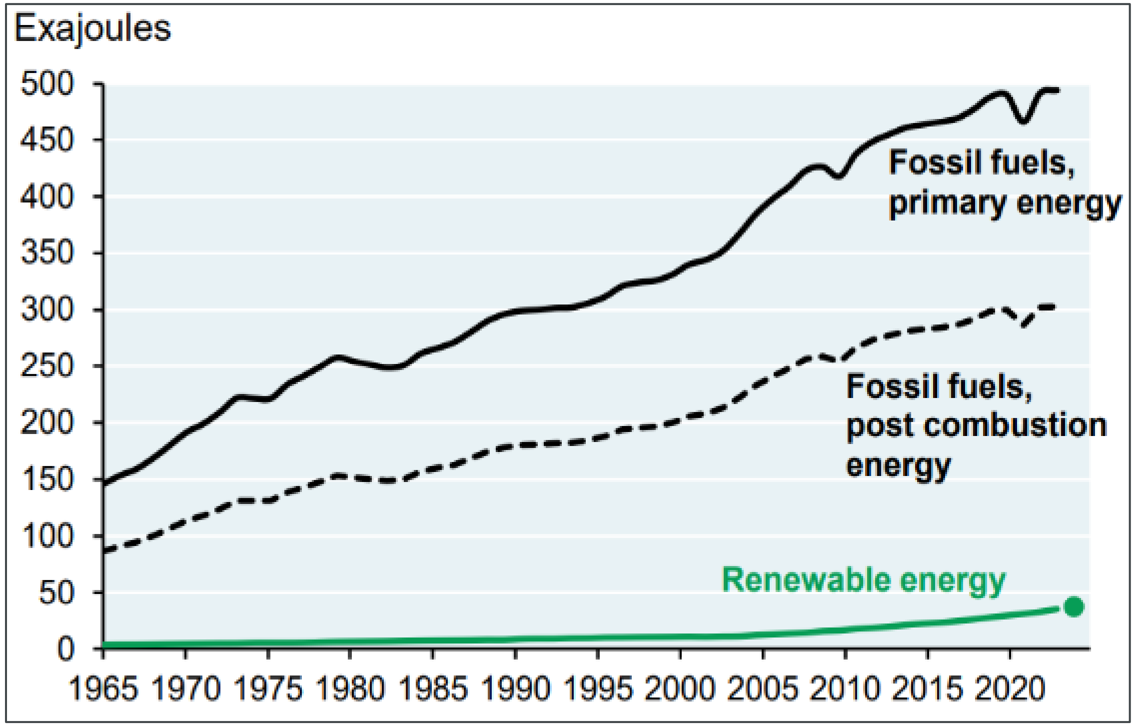
Falling fossil fuel shares mask reality of rising emissions



Although fossil fuels are falling as a proportion of global energy, they still provide over 80% of demand, driving ongoing high emissions levels.

Global fossil fuel and renewable energy use

While renewable energy is scaling rapidly and showing signs of exponential growth the scale of build out required remains daunting to significantly displace fossil fuels.

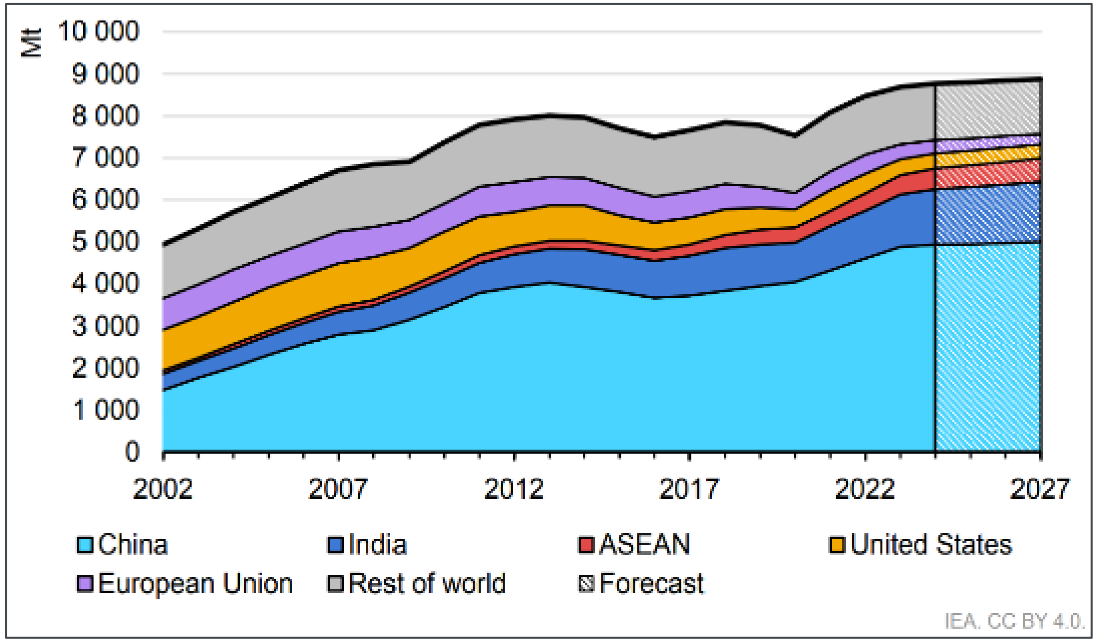


Source: JPM, Electravision

2C: 2023 – a record year for coal demand…and greenhouse gases.

Coal demand hit record highs in 2023 as did greenhouse gas levels, implying further significant committed warming at current levels of GHGs. The IEA forecast this level of demand to continue until 2027 in their latest forecast.

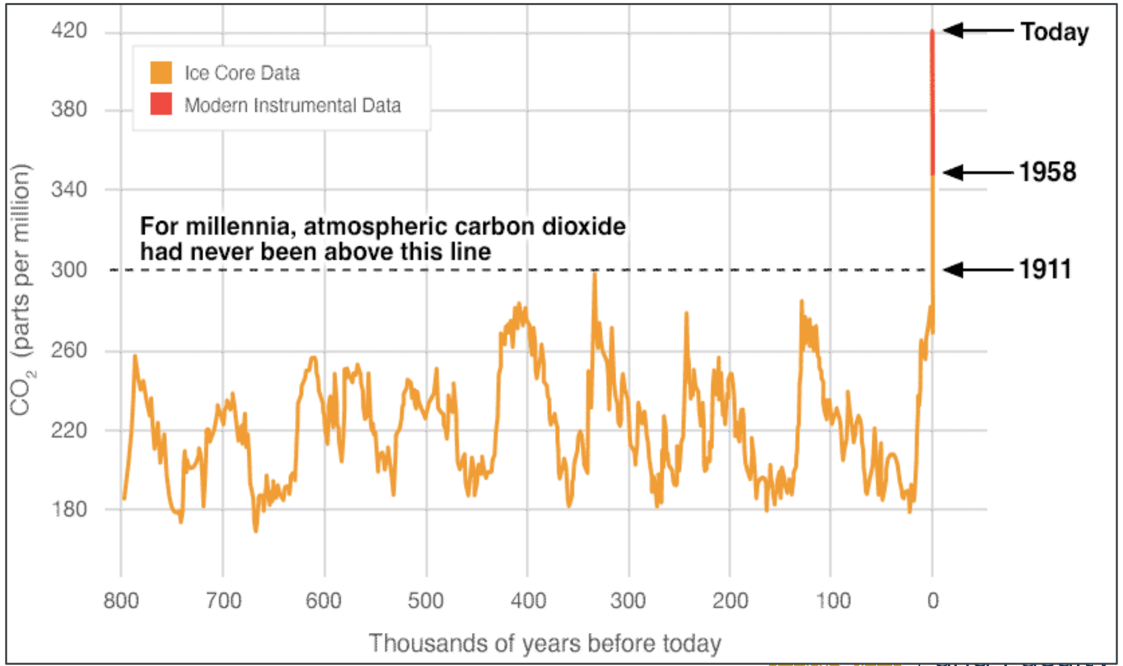
Record year for coal in 2023 and 2024, predicted to continue



2023 and 2024 saw record demands for coal globally, primarily driven by China and India, who continue to commission new coal to meet demand. Although it is likely some Chinese coal capacity is not fully utilised due to renewable build out coal use is likely to continue in the short to medium term, particularly in APAC.

Greenhouse gases hit record levels and are trending up

CO2 levels hit record highs in 2023, hitting levels not seen in human history, pre-history or beyond. Methane (the 2nd largest driver of warming) also hit record levels and is trending up. This will drive further warming.



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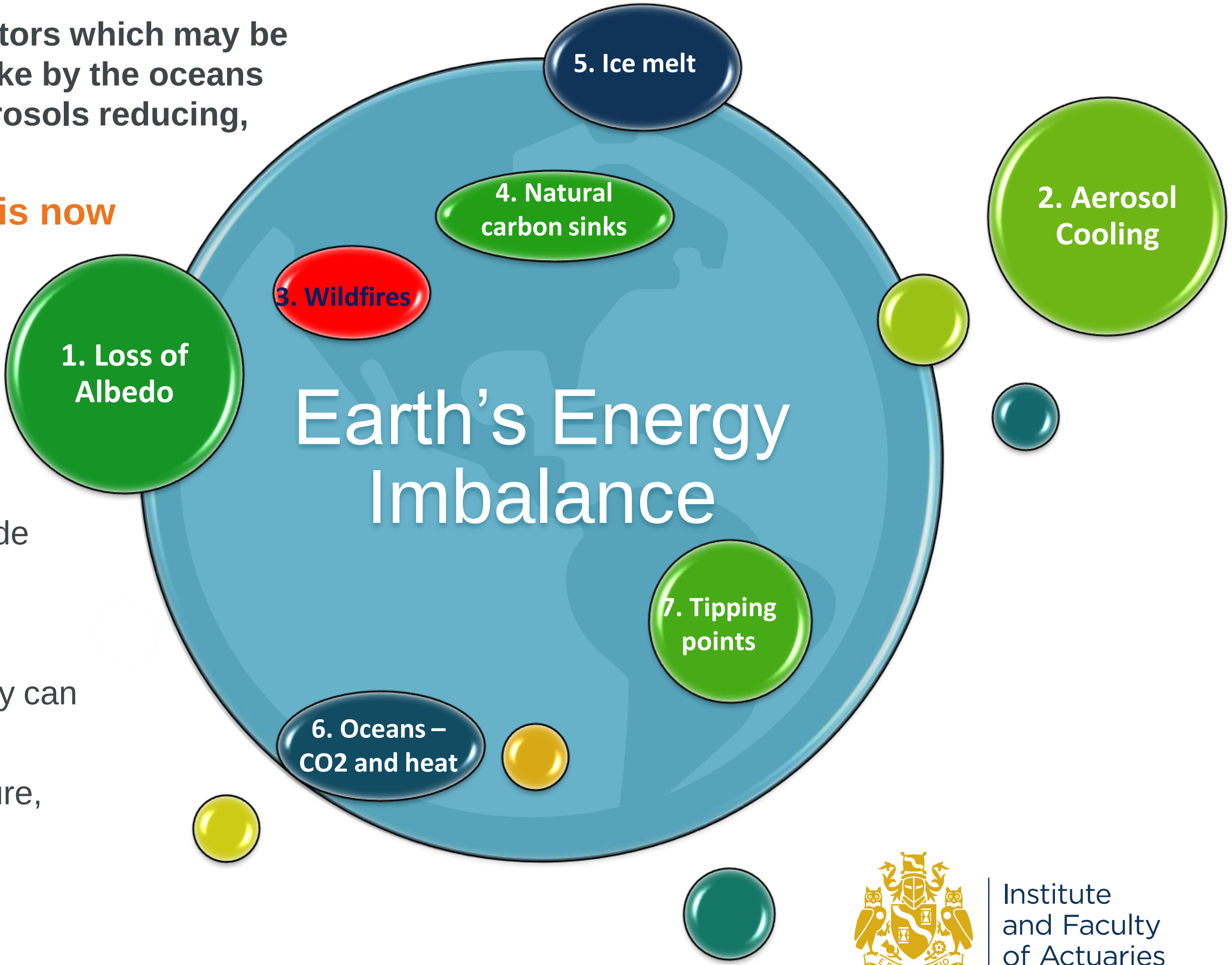
Source: IEA, Coal Report

2D: A range of factors may accelerate warming further.

As well as ongoing high emissions there are several factors which may be materially accelerating warming, including: carbon uptake by the oceans reaching a saturation point, the level of cooling from aerosols reducing, loss of albedo, tipping points, and cloud feedbacks.

It is plausible that the combined impact of these is now equivalent to a doubling of greenhouse gases.

1. **Loss of Albedo –** Earth's reflectivity reduces as ice melts, accelerating warming
2. **Aerosol cooling** – is reducing as emissions reduce, accelerating warming
3. **Wildfires** – are releasing large amounts of carbon dioxide
4. **Natural carbon sinks** – are degrading and can flip to sources, eg Arctic & Amazon
5. **Ice melt** – takes energy, once ice has melted this energy can contribute to warming
6. **Ocean CO_2 and heat uptake** – both may reduce in future, accelerating atmospheric warming
7. **Tipping points** – some release greenhouse gases, eg permafrost melt



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2E. Catastrophic levels of warming, >2°C by 2050, are likely unless immediate action is taken

An actuarial approach to a global warming projection could be to take current levels of warming and assume the rate of warming remains constant at 0.3°C. Given the range of factors that may act to accelerate warming, this could be considered as a reasonable *lower* bound with a plausible but adverse scenario assuming further acceleration, leading to Extreme warming.

Catastrophic Warming (Highly Likely)

With no further increases in the rate of warming (and no further policy action to limit warming), catastrophic warming is highly likely pre-2050:

- 2025 temperature – 1.5°C
- Decadal rate of warming - 0.3°C
- 2035 temperature – 1.8°C
- 2045 temperature – 2.1°C

Extreme warming (Possible to Likely)

Further increases in the rate of warming (and no further policy action to limit warming), imply extreme warming is possible by 2050:

- Decadal rate of warming – increases 0.2°C per decade for next 3 decades
- 2035 temperature – 2.0°C
- 2045 temperature – 2.6°C
- 2055 temperature – 3.3°C

Source: IFOA 'Climate Scorpion – the sting is in the tail'

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3. Current ‘net zero’ carbon budgets need revising as they will not limit warming to 1.5°C.

The Earth may be much more sensitive to greenhouse gases than the central assumption used in carbon budgets, implying much more warming than expected.

- 3A: Earth’s climate may be much more sensitive than thought.
- 3B: Equilibrium Climate Sensitivity – a planetary cooking experiment.
- 3C: The sting in the tail of Equilibrium Climate Sensitivity
- 3D: Developing a best estimate for rate of warming – what will actually happen?

3A: Current ‘net zero’ carbon budgets need revising as they will not limit warming to 1.5°C.

Summary

- Current temperatures demonstrate that ‘net zero’ carbon budgets, which are not themselves being achieved, are unlikely to limit warming to 1.5°C-2°C.

- Net zero carbon budgets are highly uncertain because models do not fully capture all the complexities of the Earth system and assume no ‘surprises’ such as tipping points, deforestation, large fires or increases in other greenhouse gases such as methane.

- Net zero carbon budgets were set to have a 50% (or at best 66%) chance of staying below 1.5°C or 2°C. If we set carbon budgets based on a higher probability of limiting warming, they become negative, i.e., we need to remove carbon from the atmosphere.

- The Earth may be much more sensitive to greenhouse gases than the central assumption used in carbon budgets, implying much more warming than expected by many models.

3B: Equilibrium Climate Sensitivity

A planetary cooking experiment with global consequences

Global warming is driven by the concentrations of greenhouse gases (GHGs) in the atmosphere, which are increasing due to human activity. The greenhouse effect means that there is more energy coming in (absorbed sunlight) than energy going out (heat radiated to space). This is referred to as Earth's energy imbalance. Even if we reduced emissions to zero today, because of the level of GHGs already in the atmosphere, warming would continue until the Earth reaches thermal equilibrium, i.e. a state where energy absorbed from sunlight is equal to heat radiated back out to space. However, there is uncertainty in how quickly the planet will warm (Earth's transient climate response to cumulative emissions (TCRE)) and the final temperature that would be reached (Equilibrium Climate Sensitivity (ECS)), which makes predicting the final equilibrium temperature challenging.

1. Greenhouse gas levels are the hand on the temperature setting

As GHGs increase in the atmosphere, more energy is retained by the Earth than is radiated back out to space, causing warming.

2. Earth's Energy Imbalance is the current

GHGs levels increase the current - this is called Earth's Energy Imbalance (more coming in than going out)

3. Equilibrium Climate Sensitivity (ECS) is the temperature gauge

*ECS is like the markings on the temperature control. Its as if they've been rubbed away – **we have some idea but there is significant uncertainty.***

4. Carbon budgets are the timer

Carbon budgets are like the timer – leaving the oven on for too long will burn the cake. But if we're not sure how accurate the temperature gauge is that means we're also not sure about the carbon budgets.

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Source: IFOA 'Climate Scorpion – the sting is in the tail'

3C: Earth's climate may be *much* more sensitive than thought – the sting in the tail

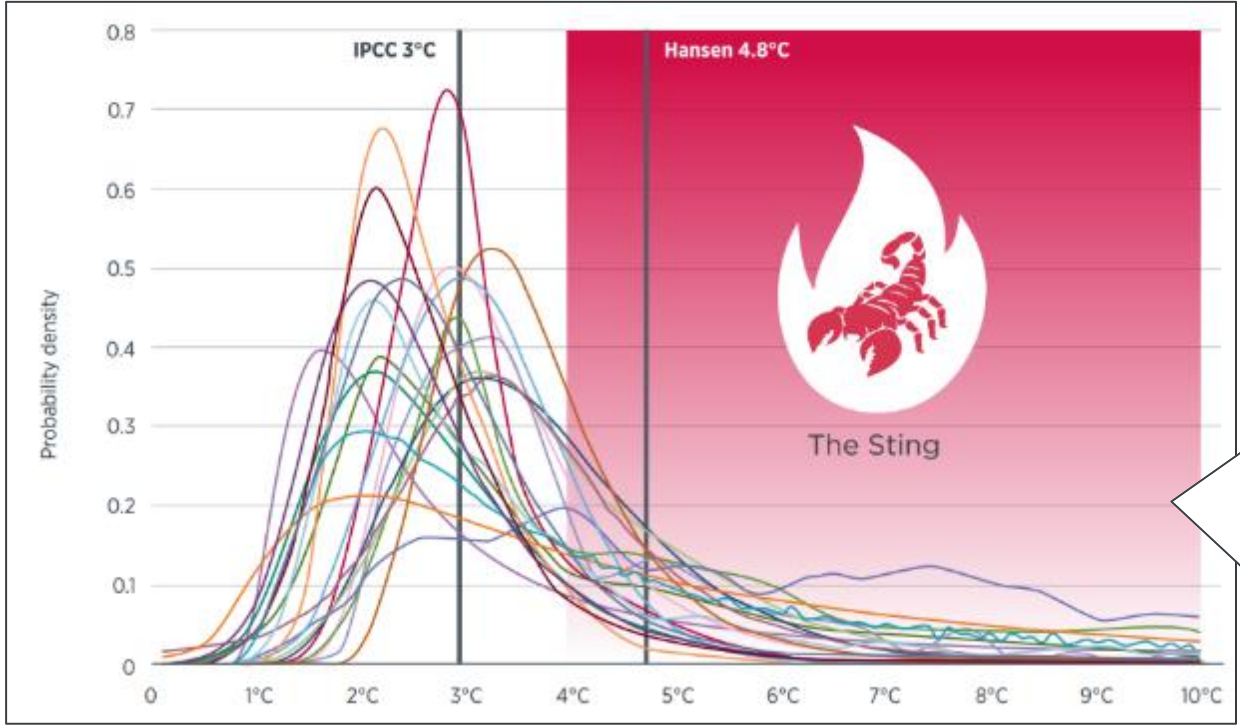
The sting in the tail of Equilibrium Climate Sensitivity

Equilibrium climate sensitivity (ECS) is the amount of warming we expect if GHG levels are doubled from pre-industrial levels. ECS was calculated in 1979 as being between 1.5°C and 4.5°C. These numbers have been remarkably stable over decades with the most recent IPCC report narrowing the range to the likely (66% to 100%) range of 2.5°C–4°C, with a best estimate of 3°C and a very likely (90% to 100%) range of 2.0°C–5°C.

However, some scientists estimate that the best estimate could be as high as 4.8°C, due to uncertainties associated with key variables, such as aerosol cooling and the rate at which ocean mixing occurs. An ECS of 3°C means that if we double GHGs, as we have effectively done (technically radiative forcing has doubled), then we would expect the planet to warm by 3°C. If the ECS is 4.8°C, then we would currently be on course for nearly 5°C of warming.

Estimates of the Probability Distribution for Climate Sensitivity

The diagram to the right shows ECS estimates from 31 models ranging from 1.83°C to 5.62°C. The diagram shows the probability distributions for ECS from these climate models, to which best estimates have been added from the IPCC and an alternative estimate from a study led by the climate scientist James Hansen.



ECS has a long tail to higher temperatures. This is due to uncertainties in the magnitude of feedbacks, such as aerosol cooling, cloud formation and break-up. Because of this uncertainty, estimates vary substantially.

Under the latest IPCC estimates there is an 18% chance of ECS being greater than 4.5°C.

This is a higher probability than the chance of failure in the game of Russian Roulette.

Source: IFOA 'Climate Scorpion – the sting is in the tail'

3D. Developing a best estimate for rate of warming – what will actually happen?

How much will we warm – and how fast?

Equilibrium Climate Sensitivity (ECS)

The warming we expect if we double GHGs from pre-industrial levels – *once Earth reaches energy balance*

- ECS now estimated at 3°C (IPCC)
- Range given of 2.5°C to 4°C
- **Heavy tailed – 18% chance ECS > 4.5°C**
- **Excludes** long-term feedbacks such as changes in ice sheets and vegetation

Earth System Sensitivity (ESS)

What will actually happen taking into account all changes

- ESS > ECS, some scientists think double
- **Implies a stunning 6°C to 10°C warming with today's GHG levels**
- Current rate of warming may increase beyond 0.3°C per decade

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Source: *IFOA 'Climate Scorpion – the sting is in the tail'*

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4. Climate change is driving increasingly severe impacts: fires, floods, heat and droughts. Climate assessments have consistently under-stated climate risks.

- 4A: Climate change is driving increasingly severe impacts: fires, floods, heat and droughts.
- 4B: Risk acceleration – entering uncharted territory.
- 4C: Climate assessments have consistently under-stated climate risks
- 4D: Flawed economic estimates of climate change damage
- 4E: Towards a more realistic assessment of climate change damage
- 4F: Climate change as a driver for interconnected risks

4A: Climate change is driving increasingly severe impacts: fires, floods, heat and droughts.

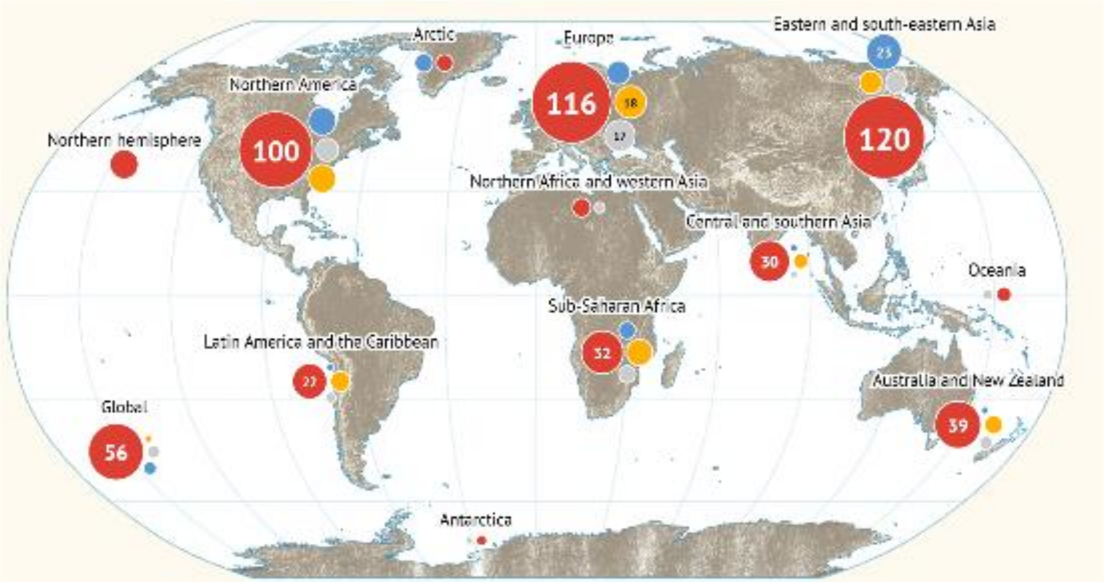
Summary

- Climate change risk position is trending to severe or catastrophic.
- Climate change is driving increasingly severe impacts sooner than expected: fires, floods, heat and droughts. This is a human security issue with food, water and heat stresses impacting populations. If unchecked, mass mortality and/or migration and/or severe economic shocks are likely.
- Climate assessments have consistently under-stated climate risks, meaning policymakers lacked information on the level of risk they accepted by agreeing the Paris goals of 1.5°C and 2°C in 2015, implicitly accepting much higher levels of risk than was understood at the time of setting these goals.
- Current approaches need expanding to deal with the high levels of risk and uncertainty. Scientists have been superb at equipping the world with detailed information on what is happening and what is likely to happen. This needs to be combined with risk expertise to assess consequences, tail events and actions required to mitigate or avoid them. Given high levels of uncertainty, this is likely to require a blend of qualitative and quantitative scenarios combined with expert judgement.

4B: Risk acceleration – entering uncharted territory.

Since 2020, there has been a steady increase of record-breaking floods, fires, droughts, storms, temperature extremes and ice loss across the globe, impacting billions of people. These and other extreme events will increase in frequency and magnitude as the planet warms further.

Global attribution map of extreme weather events



Attribution science analyses how much more likely any event is as a result of climate change. The diagram above is a screenshot of a global map of attribution studies from Carbon Brief. The numbers in Red indicate that an event was made more severe or more likely.

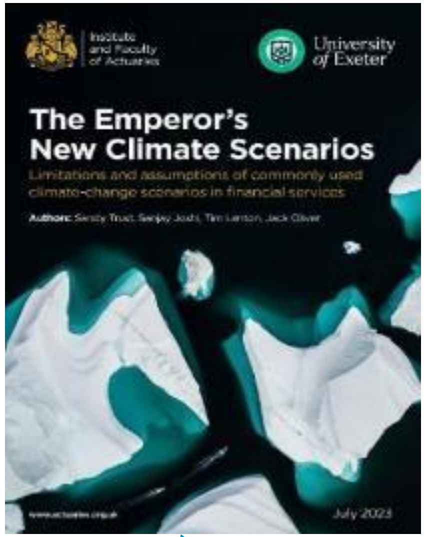
Of over 700 events studied, nearly 75% were made more severe or more likely as a result of climate change.

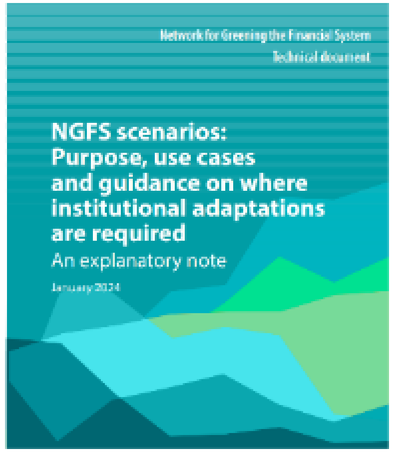
Leading to economic impacts trending towards trillions

- In 2024, natural disasters caused $320 billion of losses ($140 billion insured), the third most expensive year on record, according to analysis provided by Munich Re. The United States averages 9 billion dollar loss events per year since 1980.
- In the 5 years to 2024, the average increases to 23 billion dollar events per year, with 2023 (28 events) and 2024 (27 events), well above the historical average according to analysis provided by NOAA.
- Consultancy Verisk provides analysis on global insured and total economic losses. They estimate total economic losses now average $400 billion per annum, with a 5% chance of an annual insured loss of $250 billion or more in the next decade. Verisk estimate total losses are 3 or 4 times insured losses, highlighting both a significant protection gap and the possibility of future total economic annual losses in excess of $1 trillion.
- Lloyd's of London and Cambridge explore a climate-driven food system shock as a result of extreme weather leading to economic losses of $5 trillion. In this systemic risk analysis, they estimate losses for three scenarios ranging from major (1-in-50 year) to extreme (1-in-300 year). In the extreme scenario the 5-year global economic loss is $17.6 trillion.

4C: Climate change models are under-stating risks – further context.

2023 | 2024





Current scenarios will lead to an underestimation of the risk, potentially giving rise to a false sense of security on how the transition may unfold…current scenarios alone are not stress scenarios and so are not suitable for some financial use cases.

Policy makers and official bodies have conceded that the long-term systemic scenarios that have become the de facto standards for business and finance have serious shortcomings. They seriously understate the potential range of outcomes and fail to provide usable insights.

Many climate-scenario models in financial services are significantly underestimating climate risk…Real-world impacts of climate change are largely excluded from the damage functions of public reference climate-change economic models.

While the NGFS climate scenarios are certainly a helpful tool, they do not alleviate the responsibility of banks and other (financial) organisations to design and implement their own risk management frameworks.

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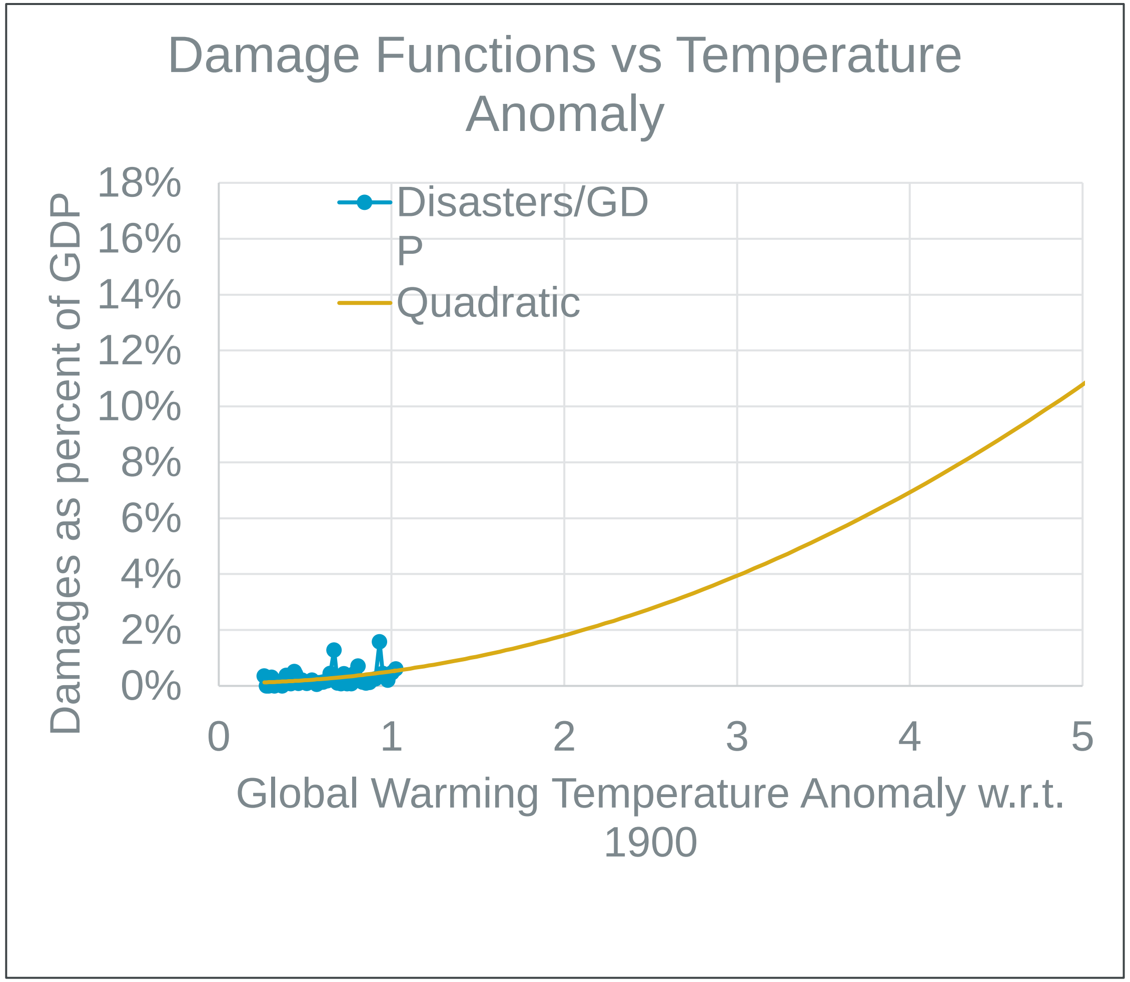
4D: Flawed economic estimates of climate change damage

Graph of GDP impact (loss) with respect to temperature



Economists have estimated the economic losses from climate change in a hot-house scenario to be *"as low as 2.1% of global economic production for a 3˚C rise in global average surface temperature, and 7.9% for a 6˚C rise."*

- **Meaning in these models, no amount of global warming impacts GDP materially**

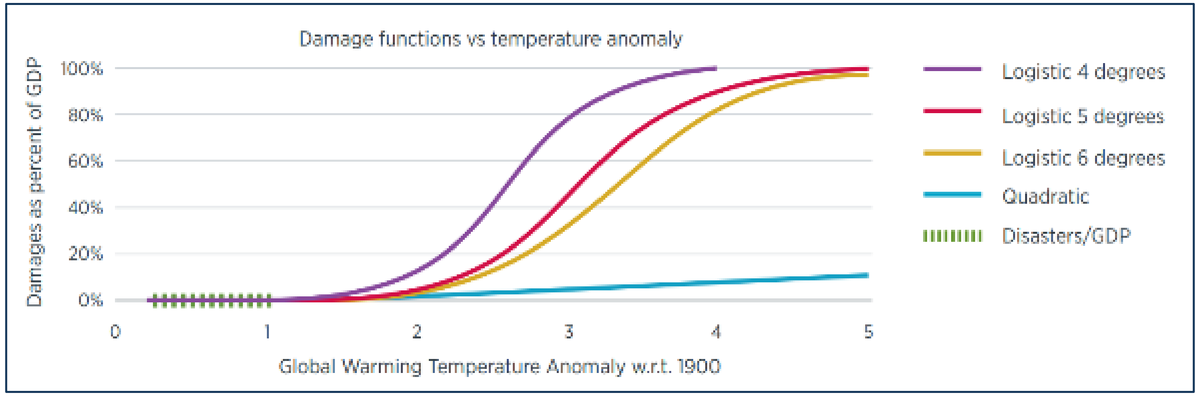
How?

- Models exclude many of the risks we expect to face, such as tipping points, sea level rise or involuntary mass migration.
- Traditional risk models often cannot account for complex network effects, leading to under-estimation of risk levels and proximity.
- Estimates exclude sectors of the economy that work inside, 87% of economy in some cases..
- General equilibrium models that underpin these results have a number of underpinning assumptions that do not hold.
- So effectively modelling 'what happened in the past when it became a little warmer', with impacts restricted to a small proportion of the economy.

4E: Towards a more realistic assessment of climate change damage

A reverse stress testing approach

A practical fix may be to 'invert' scenario analysis and use a reverse stress test approach, as used in financial services. This starts with what we want to avoid, then works backwards from there. Rather than carrying out climate-scenario analysis against a fictional world in which climate change is not happening, we could work from a new baseline of achieving the net-zero transition.



This approach shows 50% GDP destruction somewhere between 2070 and 2090 depending on how you parameterise the distribution. It is worth a moment of reflection to consider what sort of catastrophic chain of events would lead to this level of economic destruction.

This analysis provides a compelling logic for net zero policy decisions to mitigate the risk, as if we do not mitigate climate change, it will be exceptionally challenging to maintain GDP and quality of life.

Results explanation

- The quadratic damage function is what underpins the economic models described previously. This is based on damages in the future being an extrapolation of damages in the past 'when it got a bit warm'. This damage function excludes tipping points and many of the risks we expect to face. As observed from the graph, this damage function does not show significant GDP losses, even at 5˚C of warming.
- The logistic damage function assumes total economic destruction at c.6˚C but close to total at 5˚C, based on analysis provided by Carbon Tracker. This approach does not explicitly model the impact of the various risks we will face, rather it takes the approach that we will be unable to adapt beyond a certain level of warming, recognising the challenges of accurately modelling the unknown impact of tipping points and other factors.
- An alternative would be to calibrate to 90% or 80% GDP loss, assuming some adaptation that permits survival of some human population with associated residual economic activity.

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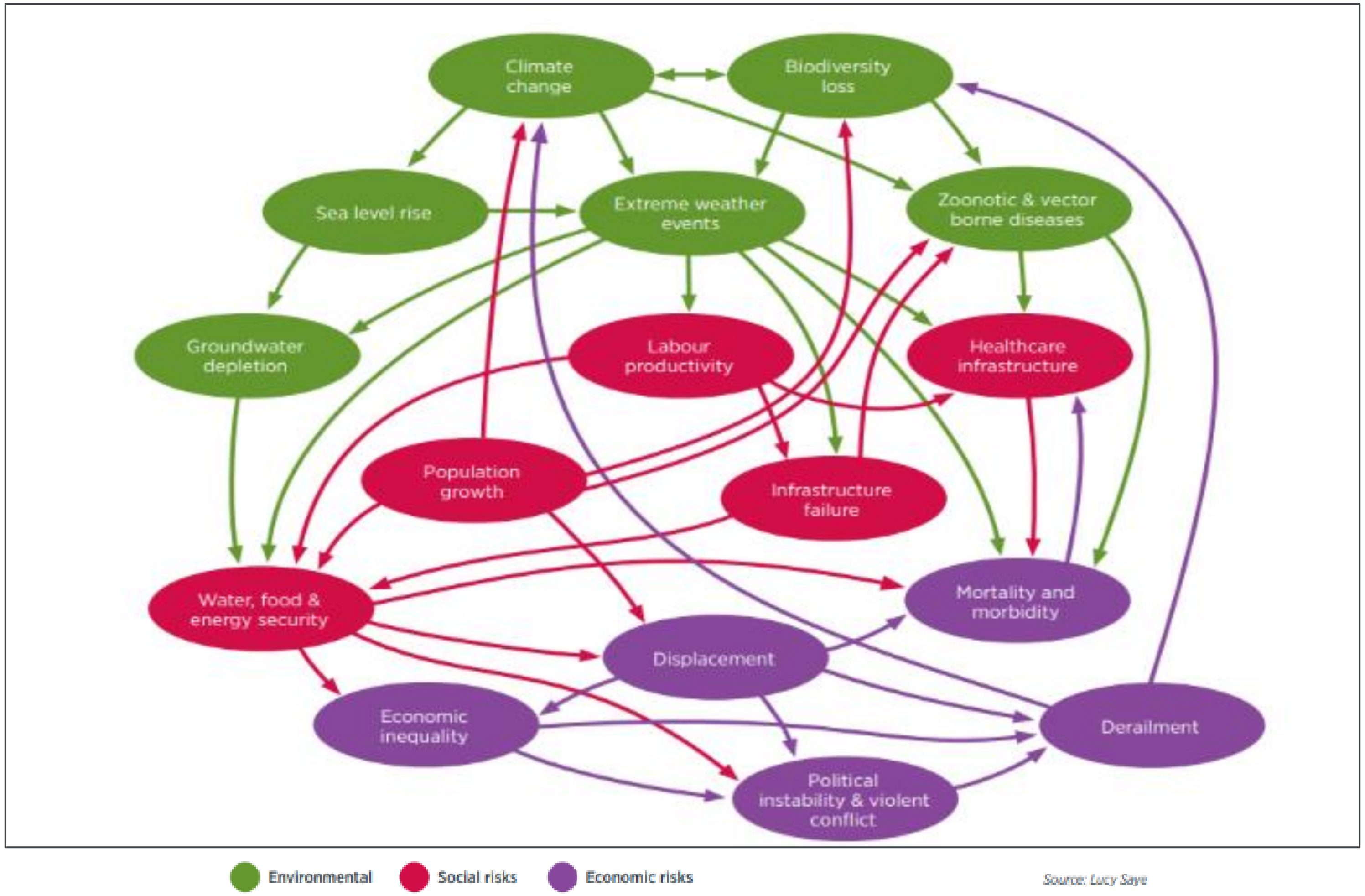
Source: *IFOA 'Climate Scorpion – the sting is in the tail'*

4F: Climate change as a driver for interconnected risks.

A causal loop diagram showing how climate risks interact



Source: Lucy Saye

- Climate change drives a complex basket of interconnected risks that could threaten the basis of our society and economy.
- Failure to consider these interconnections will lead to underestimation of risk and societal impacts.
- It is the combination of risks that may be most serious and, while it is simpler to consider risks in isolation, it is clear that, in the real world, risks are interconnected.
- Derailment risk, is the risk that response to increasingly chaotic conditions could divert focus from environmental action. This includes misinformation.

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5. Paris Goals risk triggering multiple climate tipping points as we breach 1.5°C. These include irreversible collapse of ice sheets, abrupt permafrost thaw, Amazon die back and halting major ocean current circulation. There is a point of no return beyond which it may be impossible to stabilize the climate.

- 5A: Paris Goals risk triggering multiple climate tipping points as we breach 1.5°C.
- 5B: Climate change – tipping towards the point of no return.
- 5C: Multiple climate change TPs likely to be triggered at 1.5°C.
- 5D: Nature and climate risks can interact to accelerate tipping points
- 5E: Tipping points are not independent and can interact to form tipping cascades
- 5F: There may be a point of no return beyond which it is impossible to stabilise the climate
- 5G: Impact on crop growing capability

5A: Paris goals risk triggering multiple climate tipping points as we breach 1.5°C.

Summary

- Warming above 1.5°C is extremely risky. The chance of triggering multiple climate tipping points cannot be ruled out, such as the irreversible collapse of ice sheets, abrupt permafrost thaw, Amazon die back and halting major ocean current circulation.

- Impacts could be catastrophic, including significant loss of capacity to grow major staple crops and multi-metre sea level rise. Some tipping points act to accelerate climate change through release of greenhouse gases, loss of carbon sinks or further loss of reflectivity. Others, such as AMOC collapse, might change the pattern of climate change.

- Tipping points may interact to form tipping cascades, which would further accelerate the rate of warming and severity of climate impacts. If multiple tipping points are triggered, there may be a point of no return, after which it may be impossible to stabilise the climate.

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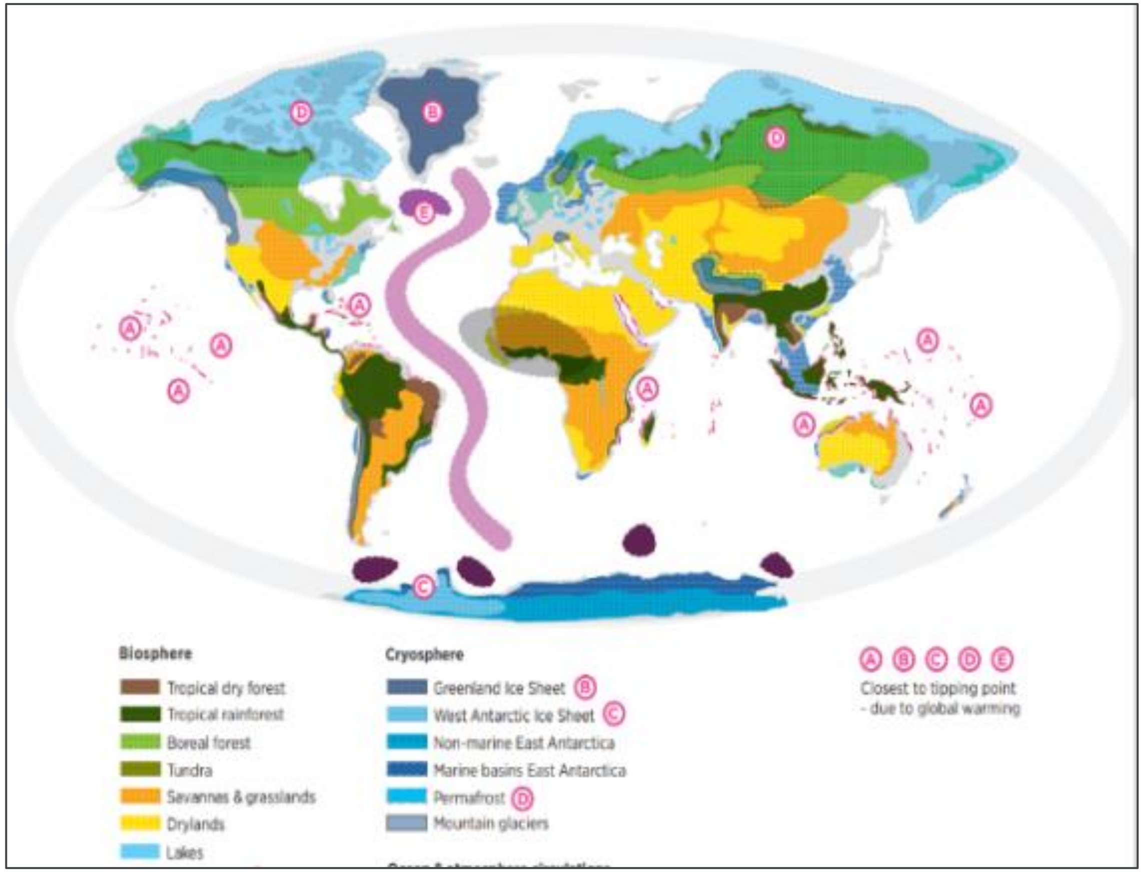
5B: Climate change – tipping towards the point of no return.

Tipping Points identified in Global Tipping Points report



Warming above 1.5°C is dangerous, increasing the risk of triggering multiple climate tipping points

- Tipping points include: collapse of ice sheets in Greenland, West Antarctica and the Himalayas, permafrost melt, Amazon die back and the halting of major ocean current circulation.
- **Passing these thresholds may constitute an ecological point of no return, after which it may be practically impossible to return the climate to pre-industrial (Holocene) stability.**
- Tipping points may interact to form tipping cascades, that act to further accelerate the rate of warming and climate impacts.
- There are indicators we are now approaching some tipping points, as illustrated in the diagram. This identified five Earth systems at risk of crossing tipping points at current levels of warming: coral reef loss, the Greenland and West Antarctica ice sheet, Permafrost melt and the collapse of the sub-polar gyre.
- Tipping points are particularly important because, if triggered, we may find the climate moves into a different state that we no longer have the ability to impact by reducing our emissions.
- **This threat of negative impacts associated with abrupt and/or irreversible changes, and the potential for cascading effects, including amplification of global warming, make the prospect of breaching tipping points an existential risk.**

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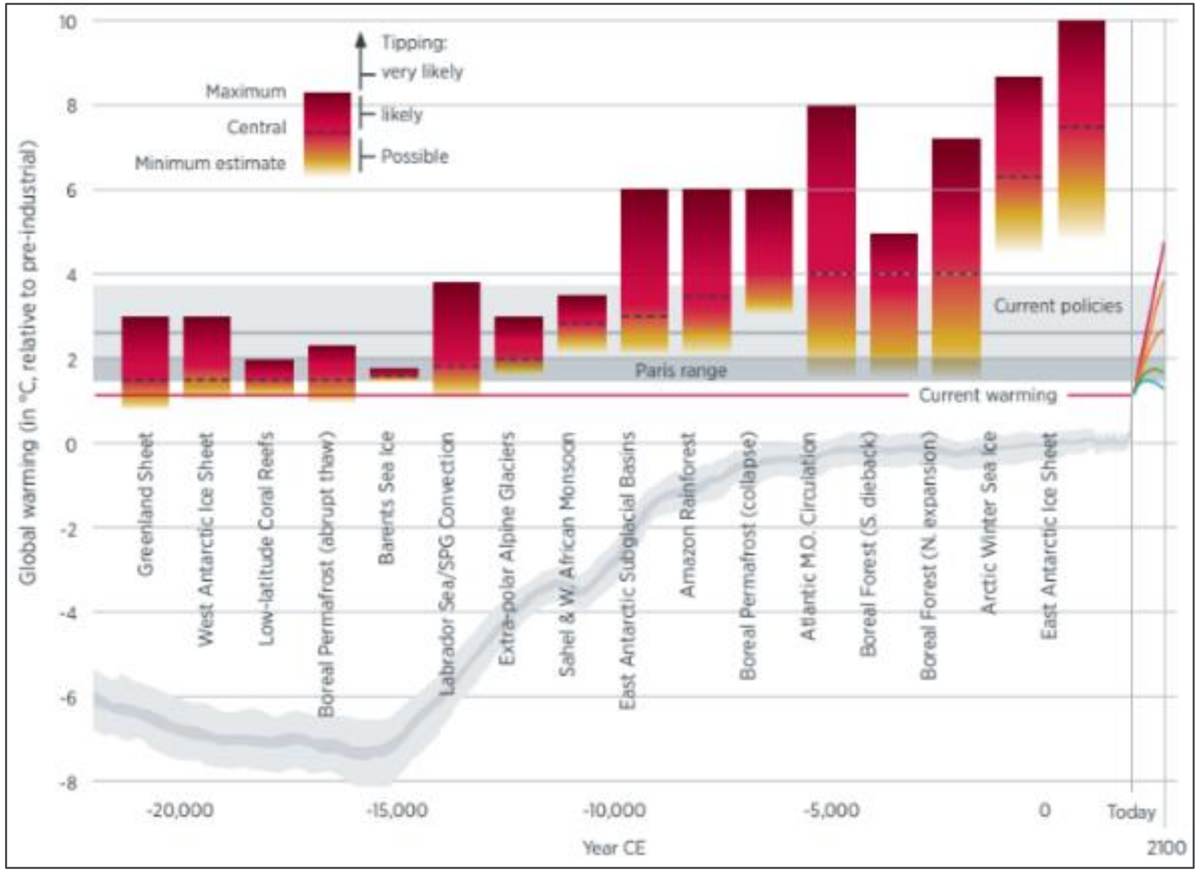
Sources: *Global Tipping Points report, 2023*

5C: Multiple climate change TPs likely to be triggered at 1.5°C.

Climate tipping points and the temperature at which they may tip



Warming above 1.5°C is dangerous, increasing the risk of triggering multiple climate tipping points

- Six CTPs likely to be triggered in Paris Agreement range (1.5-2°C).
- It re-emphasizes how important it is to treat 1.5°C as a physical limit and not a political target, recognizing the risk from tipping points.
- Four of these are showing scientific evidence of now being at risk already at 1.5°C.
- These tipping points may interact, triggering each other and cascading like dominoes. Once triggered, they may be irreversible and may act to accelerate global warming.
- This could be by a number of different effects, for example increasing GHGs, lowering albedo or redistributing heat in the ocean. This could increase the severity of impacts (e.g. accelerating multi-metre sea level rise).

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Sources: *Armstrong et al. (2022) Exceeding 1.5°C global warming could trigger multiple climate tipping points*

5D: Nature and climate risks can interact to accelerate tipping points

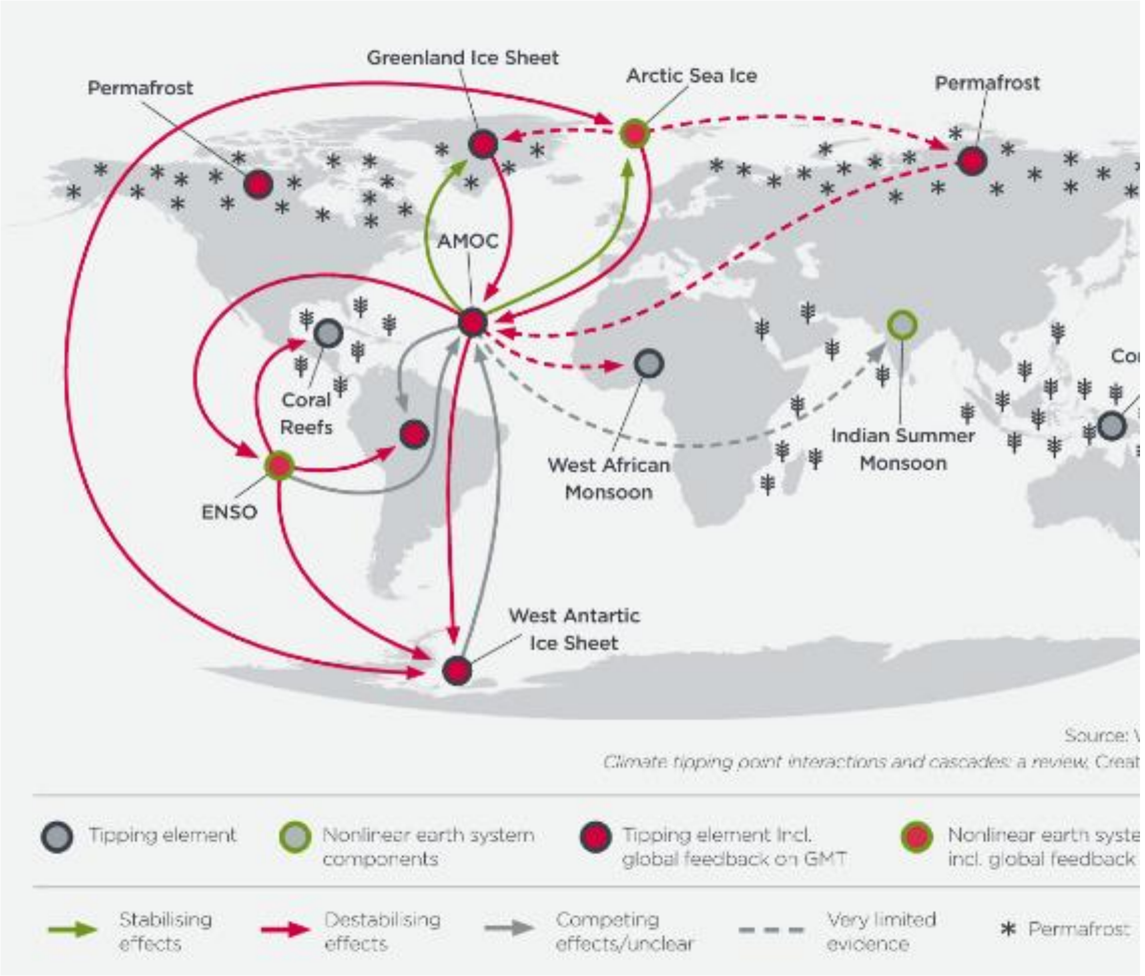
Amazon causal loop diagram

- The Amazon is a complex web of hydrological systems and ecosystems and is considered a critical Earth system. It's home to more than 10% of Earth's biodiversity and holds more than the equivalent of 15-20 years of (2024) global carbon dioxide emissions.
- In 2021, research showed the southeastern Amazon became a carbon source - emitting more carbon emissions than it absorbed. A combination of both increasing temperatures and deforestation risks breaching a tipping point, causing the dieback of large amounts of the Amazon rainforest and a shift into a dry savannah.
- The table below illustrates how significant the impact of deforestation is on the temperature at which this may occur, bringing it forward from 3C of warming to near current temperatures.

	Temperature	Deforestation rate
Current	+1.2°C (20-year average)	17%
Tipping Point [before accounting for deforestation]	**+3°C to 5°C**	**[unaccounted] %**
Tipping Point [allowing for deforestation]	**+1.5°C to 2°C**	**20-25%**

5E: Tipping points are not independent and can interact to form tipping cascades

Tipping point interactions



- There are multiple interactions between tipping points that risk triggering ‘cascades’ – where tipping points trigger one another like dominoes. The collective effect of these interactions is to lower the temperature threshold at which a tipping point is triggered.
- The diagram illustrates these interactions and the potential for tipping cascades, with red arrows indicating a destabilising influence.
- Tipping points with a red circle indicate they will accelerate warming, either through loss of albedo (e.g. Arctic sea ice) or release of GHGs (e.g. permafrost melt).

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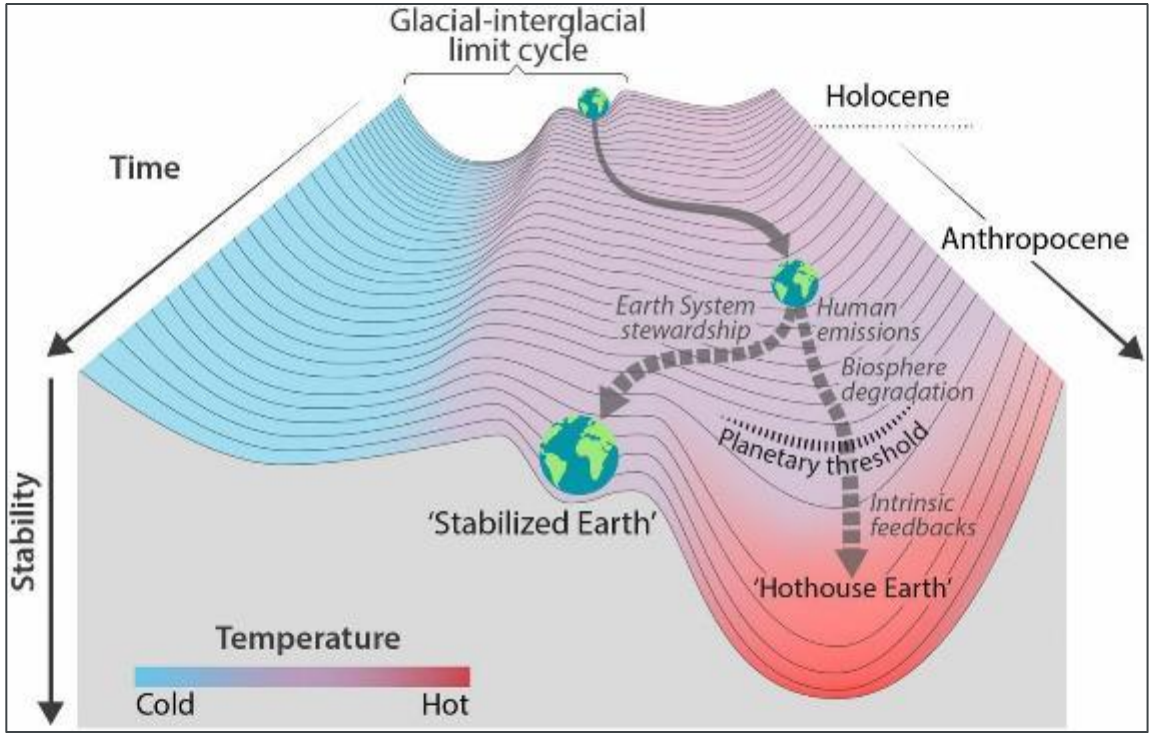
Sources: *Wunderling et al. (2024) Earth system dynamics*

5F: There may be a point of no return beyond which it is impossible to stabilise the climate

Potential for a hothouse Earth planetary system state



- Earth has been oscillating between colder and warmer periods over a million years (the entire Pleistocene), but the average mean temperature has never exceeded 2 C (interglacial) above or 6 C below (deep ice age) the preindustrial temperature on Earth (14 C), reflecting the importance of feedbacks from the living biosphere as part of regulating the temperature dynamics of the Earth.
- There is increasing consensus that pushing the Earth system to more than 2 C warming compared to pre-industrial levels constitutes unknown terrain for contemporary societies and a threat to civilization.
- The impacts of a Hothouse Earth pathway on human societies would likely be massive, sometimes abrupt, and undoubtedly disruptive.

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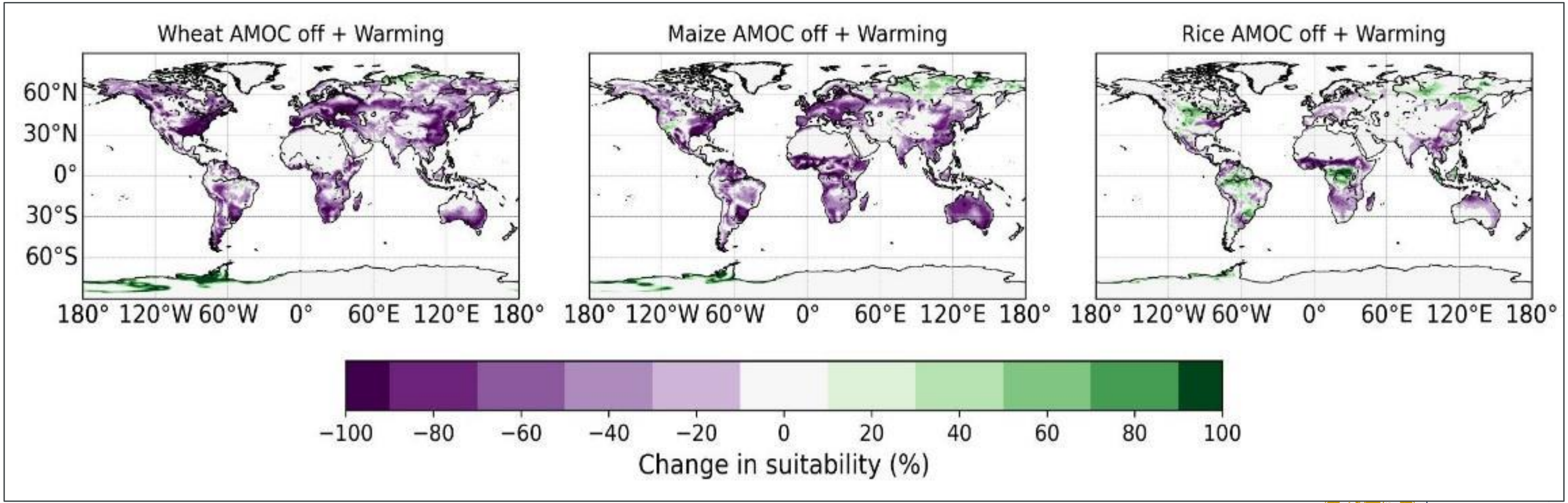
Sources: *Steffen at al, 2018* Trajectories of the Earth System in the Anthropocene | PNAS

5G: Impact on crop growing capability

Research into the impact of one tipping point (AMOC collapse) indicates significant (50%) reduction in the ability to grow major staple crops in the Northern Hemisphere due to the changed climate. As the AMOC transfers huge amounts of heat North, its collapse would act to reduce temperatures in the Northern Hemisphere. A side effect would be more heat remaining in the Southern Ocean, accelerating ice melt in Antarctica.

Wheat **Maize** **Rice**



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6. Policy action required to reduce emissions, accelerate energy transition, adapt and mitigate risk. The energy transition is accelerating with economic solutions now available. The pace can be increased or decreased by policy incentives.

- 6A: Policy action to reduce emissions, accelerate energy transition, adapt and mitigate risk
- 6B: Energy transition investment grew 17% in 2023 to £1.77 trillion.
- 6C: Geopolitics and energy security. Nature as an ally.
- 6D: Positive socio-economic tipping points can be accelerated with policy support

6A : Policy action to reduce emissions, accelerate energy transition, adapt and mitigate risk

Summary

- The energy transition is accelerating with solutions now available and cost competitive. The pace can be increased by policies that work to leverage cross-sectoral positive socio-economic tipping points and restore natural carbon sinks.

- Simultaneously policy action accompanied by regulation to reduce emissions as close to zero as possible is required. This should include accelerated phase out of fossil fuels, action to reduce methane emissions and protection of carbon sinks.

- Nations will need to adapt in order to be resilient to future shocks. Adaptation priorities should be informed by realistic risk assessments, carried out in line with best practice risk management principles and provided to global, regional and national authorities.

- To inform policy options to mitigate risk, policymakers should commission research on a full range of risk mitigation options, including greenhouse gas removal and solar radiation management.

- Research should consider synergies and trade offs of mitigation options with other risk areas, including the need for just transitions.

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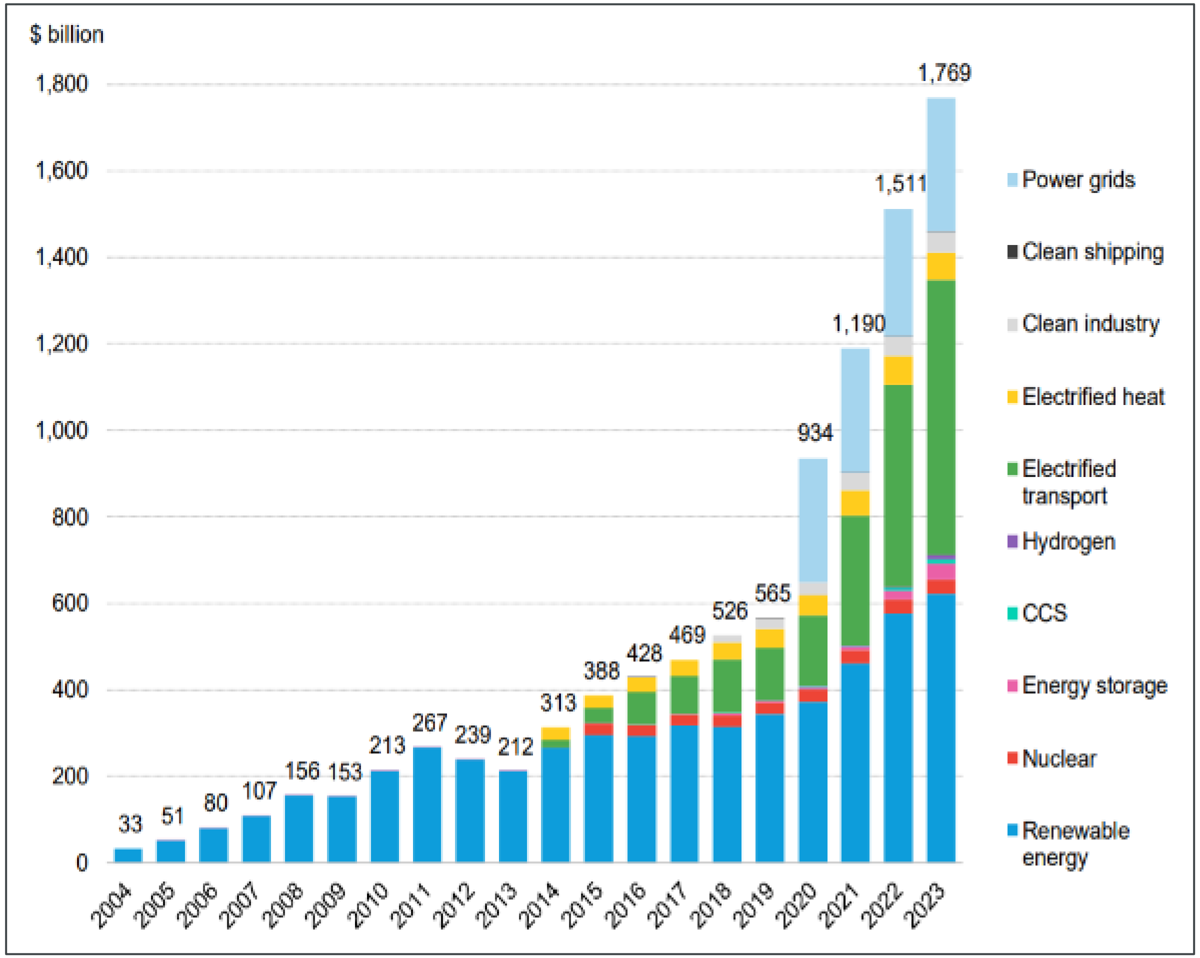
6B : Energy transition investment grew 17% in 2023 to £1.77 trillion

Global investment in energy transition, by sector



Steady YOY increases in transition investment

- **$1.7 trillion investment in 2023, increase of 17%**
  This covers deployment of clean technologies such as renewable energy projects, electric vehicles, power grids and hydrogen. This compares with around $1 trillion of fossil fuel investment.
- **Including debt total investment is around £2.8 trillion**
  Including investment in the clean energy supply chain, venture capital, private equity and public markets investment in climate-tech companies, and corporate and sovereign debt issuance for energy transition purposes this figure increases to nearly $3 trillion.
- **China the largest market, Europe saw fastest growth.**
  China comprises 38% of the global total at $676 billion. US posted strong growth to narrow gap, spending $303 billion. 27 EU members saw combined $340 billion in investment.
- **Led by EVs, Renewables and Grids**
  EVs largest category at $634 billion, Renewables a close second with $623 billion and Grids in bronze position with $310 billion.

Sources: *Bloomberg NEF*

6C: Geopolitics and energy security. Nature as an ally.

Renewable costs continue to fall with uptake accelerated in some geographies by supportive policies. Natural carbon sinks and sources are significant, leveraging and/or regenerating natural carbon sinks will be essential to successfully mitigating climate change.

Renewable energy potential is significant

…and could help to address energy security concerns.

COP28 statement on climate, nature and people

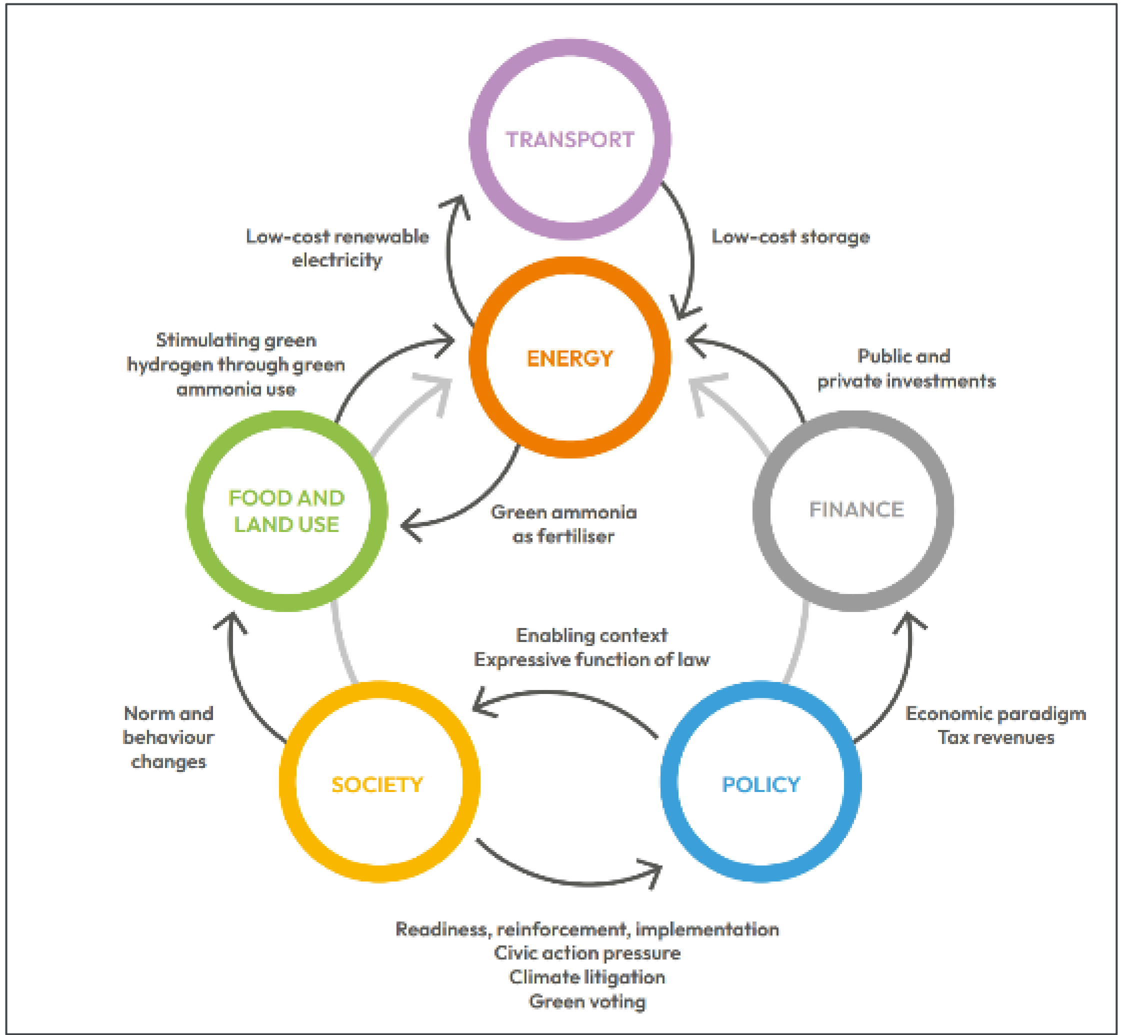
"There is no path to achieve the Paris Agreement or the 2030 goals and targets of the Kunming-Montreal Global Biodiversity Framework without urgently addressing climate change, biodiversity loss and land degradation together.'

- Growing and projected impacts of **climate change critically threaten biodiversity** and the billions of livelihoods dependant on high-integrity ecosystems.
- Continued loss and **degradation of nature increases climate vulnerability and contributes to significant greenhouse gas emissions** and impedes sustainable development.
- Efforts which promote sustainable land management, drought resilience and ocean health **provide cross-cutting benefits to action on climate change**, biodiversity loss, and sustainable development.
- Acting on climate change, biodiversity loss, land degradation and ocean health provides mutually reinforcing **benefits for increasing resilience and securing sustainable livelihoods, while reducing negative trade-offs**.

Sources: *Carbon Tracker, The sky's the limit*

6D: Positive socio-economic tipping points can be accelerated with policy support

Diagram of positive tipping cascades



Targeted policies can accelerate tipping cascades

- **Cross-system interactions within sociotechnical, socioecological and sociopolitical systems can lead to positive tipping cascades.** The interactions across society, policy, technology and economy can amplify these.
- **In the near term, cascades across those systems can also lead to rapid decarbonisation.** For instance, public procurement of sustainable food can accelerate norm and behaviour changes, enable the use of practices such as regen ag or green ammonia use, by reducing the land pressure, and (with the latter) can help decarb of energy and transport by boosting the green hydrogen production.
- **Similarly, zero emission vehicle (ZEV) mandates are a strong leverage point due to cascading effects.** As manufacturers meet ZEV targets, they overcome supply constraint in transport, facilitate decarbonisation in the energy sector through innovation and raise demand. Versions of this policy have proved highly effective in California, China and Canada (Quebec and British Columbia), combined with charging station installation.

Sources: *Global Tipping Points report, 2023*

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Climate Change Supplementary Material

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