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Quantifying the climate crisis: a data-driven framework using response indicators for evidence-based adaptation policies

Gianluca Alimonti ^a and Luigi Mariani ^b

^aINFN&Università degli Studi, Milano, Italy; ^bUniversità degli Studi, Brescia – Dicatam, Brescia, Italy

ABSTRACT

The concept of ‘climate crisis’ has a long history and has been increasingly employed by media and politics in recent decades, shaping collective perceptions of climate variability and change. However, in the absence of a critical definition, it risks fostering unrealistic interpretations – either alarmist or overly optimistic. To promote a rational understanding of ‘climate crisis’ we propose a framework of Response Indicators (RINDs) based on the IPCC AR6 Climate Impact Drivers (CIDs).

The Mann-Kendall trend test applied to RIND time series reveals that most indicators do not exhibit statistically significant worsening trends. This challenges crisis narratives in specific contexts and highlights the need for localised, data-driven adaptation strategies rather than generalised alarm. We advocate annual updates of indicators to create an evolving ‘crisis index,’ mirroring the shift in economics from qualitative crisis definitions (e.g. recessions as ‘two consecutive GDP quarters’) to a quantitative metrics.

Such an approach would help prevent subjective uses of ‘climate crisis’ while enhancing the scientific reliability of the concept; it would also acknowledge regional variability and prioritise targeted interventions over blanket terminology. By linking ‘crisis’ to measurable benchmarks, policymakers gain clearer adaptation priorities.

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Climate crisis; climate emergency; response indicators (RIND); Climate Impact Drivers (CID); metrics for climate crisis

What gets us into trouble is not what we don't know
It's what we know for sure that just ain't so
Mark Twain

1. Defining the Concept of ‘Climate Crisis’ Through Measurable Indicators

The paper proposes an analytical approach to the concept of climate crisis through a set of objective, measurable Response Indicators (RINDs), such as environmental

CONTACT Gianluca Alimonti  Gianluca.Alimonti@unimi.it  INFN&Università degli Studi, Via Celoria 16, Milano 20133, Italy

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anomalies, socio-economic and health impacts, driven by Climate Impact Drivers (CIDs) defined in IPCC AR6. By shifting the focus from subjective interpretations to a quantifiable metrics, this approach provides a critical framework for assessing the situation in an analytical manner. Policymakers can use these indicators to design targeted interventions that address specific environmental changes, ensuring that actions are data-driven and aligned with scientific evidence. This definition avoids alarmism while promoting practical, evidence-based solutions.

2. Balancing Mitigation and Adaptation in Policy Design

A balanced approach that integrates both mitigation and adaptation strategies is essential to address climate variability and change. Rather than prioritising one over the other, this perspective acknowledges that effective climate policy should encompass both, preparing for possible impacts. For example, policies could include incentives for renewable energy development alongside investments in resilient infrastructure and community preparedness programs. This balanced framework ensures that resources are allocated efficiently, addressing the consequences of climate change, which are and will continue to be present, in a measurable and sustainable way.

3. Promoting Long-Term Society Sustainability Through Innovation

Fostering innovation is essential to mitigate the effects of climate change and to address its consequences through adaptation strategies. Rather than framing the issue solely as a threat, this approach emphasises the potential for technological and systemic advancements to create sustainable solutions. Policies could include funding for research and development in areas such as renewable energy storage and sustainable agriculture. By encouraging collaboration between governments, industries and academia, this approach aims to unlock new pathways for societal sustainability. The emphasis on innovation shifts the narrative from urgency to opportunity, highlighting the potential for progress without resorting to alarmist rhetoric.

1. The climate crisis concept

The concept of crisis has a long history; it is polysemic and highly multifaceted, as shown in Supplementary Material Appendix 1. It is used across various contexts and scales with differing meanings, to the point that extending the concept of crisis to climate becomes arbitrary in the absence of a rigorous metrics.

The IPCC itself acknowledged this issue and considers 'climate crisis' a media term:

Also, some media outlets have recently adopted and promoted terms and phrases stronger than the more neutral 'climate change' and 'global warming', including 'climate crisis', 'global heating', and 'climate emergency'. Google searches on those terms, and on 'climate action', increased 20-fold in 2019, when large social movements such as School Strikes for Climate gained worldwide attention. (IPCC-AR6-WG1, 2021, p. 173)

Google search trends for the terms 'climate crisis' and 'climate emergency' are shown in [Figure 1](#) where, in addition to the 2019 increase addressed by IPCC, a previous surge is evident, coinciding with the film *'An Inconvenient Truth'* by Al Gore is evident.

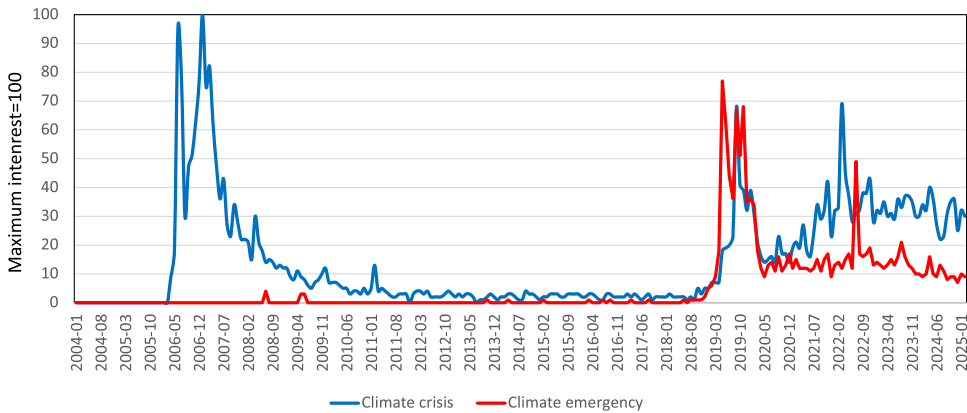


Figure 1. Google search term usage for ‘Climate crisis’ and ‘Climate emergency’. Numbers represent search interest relative to the highest point on the chart for the given time. A value of 100 is the peak popularity for the term (Google, 2004).

These data suggest the hypothesis that the concept of the ‘climate crisis’ was first introduced by Al Gore and later adopted by the Fridays for Future movement (as noted by the IPCC). In Al Gore’s film, the term ‘climate crisis’ is not explicitly mentioned, although its existence and severity are strongly implied throughout. However, the slogan ‘*The climate crisis can be solved*’ appears in written form at the end of the film, summarising the key concepts expressed and just before it is noted that humanity had already resolved the environmental crisis of the ozone hole. The film begins with a quote by Mark Twain, which is also placed at the beginning of our article as lends itself well to the ‘climate crisis’ issue.

The metrics used to define a particular phenomenon can be either heuristic or analytical (Evans, 1984): as an example, a heuristic metrics leads us to recognise a thunderstorm intuitively, whereas an analytical metrics derives the definition of a thunderstorm from the observation of a series of morphological characteristics relevant for taxonomic purposes (such as deep convection, lightning, cumulonimbus clouds, showers, wind bursts, and so on).

The heuristic ‘climate crisis’ metrics was adopted for periods characterised by long cold phases, when crop failures, the need to supply large quantities of firewood, and the virulence of cold-related diseases increasingly limited the survival of populations at mid and high latitudes. Warm phases were referred to as climate optima, while cold phases were regarded as climate crises. In this context, the late Middle Ages are emblematic, as they witnessed a significant increase of European inhabited centres, with expansion both in altitude and towards higher latitudes (Behringer, 2009). According to Le Roy Ladurie (2004), the onset of the Little Ice Age (LIA) coincided with the first major food crisis in Central Europe during the second decade of the fourteenth century, marking the end of the Middle Ages’ ‘golden age’: floods struck Europe from 1312 to 1320, causing the complete failure of the European cereal harvest in 1315–1316. The LIA was then accompanied by the appearance of the Black Death in Europe in 1347, whose peak mortality, due to the pneumonic form of the plague, occurred during the cold semester (Washington, 2024). The Black Death remained endemic in Europe for most of the LIA, confirming the role of cold phases in the spread of the disease.

The discovery of ice ages in the nineteenth century by Swiss geomorphologist Agassiz sparked public concern about the possibility of a cold phase that could threaten humanity's survival (Ateş, 2022). This concern resurfaced in the 1970s, when a drop in global temperatures, as noted by H. H. Lamb in *Unesco Courier* (Lamb, 1973), raised fears about serious food security issues, particularly with regard to global rice production, as highlighted by Huke (1976).

From the 1980s onwards, coinciding with a significant rise in global temperatures, the notion that warm phases might be harmful to humanity gained traction in public opinion, the media, and politics, leading to psychological distress for many individuals (Sasser, 2024).

An analytical proposal based on indicators that attempts to provide a quantitative definition of the 'climate crisis' was made by Ripple et al. (2020) and updated in 2022 (Ripple et al., 2022). Various indicators were presented, such as global human population, total fertility rate and others, which may eventually lead to considerations about the state of global societal well-being but have little relevance to a systemic metrics for defining a climate crisis. The increasing trends of some of these indicators, per capita meat production, air transport passengers or global GDP, could potentially be interpreted as improvements in general living conditions and might therefore contradict the thesis the authors aim to support.

A 'climate crisis' position is often adopted by political figures as testified by this statement from the U.N. Secretary-General: *'The era of global warming is over; the era of global boiling has arrived. The air is unbreathable, the heat is unbearable and the level of profits from fossil fuels and climate inaction is unacceptable'* (Guterres, 2023). This position should be interpreted in light of the considerations expressed by J. Skea, current IPCC Chair: *'If you constantly communicate the message that we are all doomed to extinction, then that paralyses people and prevents them from taking the necessary steps to get a grip on climate change'* (SKEA, 2023)

A consequence of what is now widely perceived as a 'climate crisis' is the emergence of 'climate emergency declarations', actions taken by governments to acknowledge that humanity is facing a climate crisis (Wiki, 2025). The first such declaration was made in December 2016 by the local council of Darebin, in the northern suburbs of Melbourne (Cace, 2013). Since then, it has become a significant social phenomenon: as of August 2024, jurisdictions that have declared a climate emergency amount over 2,364 local governments in 40 countries, covering more than 1 billion citizens (Ceda, 2019).

A more optimistic vision is instead expressed by Lomborg (2020) who underlines the positive aspects of the current phase of global economic development.

We wonder whether, in light of this lack of a rigorous foundation for the 'climate crisis' concept, it is possible to propose an analytical approach based on both Climate Impact-Drivers (CIDs) and Response Indicators (RINDs), with the purpose of stimulating a future discussion and a better framework.

Depending on the spatial and temporal variation of different CIDs, there will be corresponding RINDs which can be summarised as a set of meteorological, climatic, and hydrological impacts, as well as mortality from natural disasters (Alimonti & Mariani, 2023). It should be noted that RINDs and mortality from natural disasters are generally a product of socioeconomic conditions confronted by extreme weather events (e.g. the risk of forest fires is driven not only by meteorological variables but also by forest

management strategies; the risk of floods is closely related to mitigation works like rivers embankments, dams, retention basins and land management strategies); nevertheless these can be selected as a first approximation climate response indicators.

The work has been divided into two parts: CIDs will be analysed in the first part and RINDs in the second. Throughout our work, we considered the distinction between the interannual variability typical of a stationary climate (e.g. El Niño) and climate change (Stuecker 2023).

2. Data and methods

The taxonomic approach outlined in IPCC AR6 (IPCC-AR6-WG2, 2022, p. 2424) has been used to categorise different impacts; specific data have been gathered from the Centre for Research on the Epidemiology of Disasters (CRED), Our World in Data (OWD), World Bank, and international literature. The main types of data sources include forest inventories, monitoring systems, remote sensing and thematic mapping, administrative records and specific surveys.

A special role in our analysis is played by the international disaster database EM-DAT (Emergency Events Database (EMDAT, 1988)) managed by CRED; relevant details for this work have been presented in a previous article (Alimonti & Mariani, 2023). Two main disaster groups are distinguished in EM-DAT: natural and technological disasters. This paper deals only with natural disasters and in EM-DAT they are classified into six subgroups: Climatological, Hydrological, Meteorological, Biological, Geophysical, and Extra-terrestrial disasters.

It is important to consider that EM-DAT trends in disaster data are affected by a strong 'better reporting' bias (Alimonti & Mariani, 2023; EMDAT, 2025; Ritchie & Rosado, 2024), to the point that since September 2023 on the EM-DAT site it can be read:

Technologies and initiatives can be considered responsible for the dominant trend observed. Therefore, it is challenging to infer insight into the actual drivers of disasters such as climate change, population growth, or disaster risk management. Accordingly, excluding pre-2000 data from trend analyses based on EM-DAT is strongly recommended. (EMDATsb, 2025)

Based on this, we analyse EM-DAT events occurring after the year 2000.

Trend analysis were conducted with the Mann-Kendall (MK) test module of the PAST software version 4.17c (Hammer et al., 2001) which implements the algorithm described by Gilbert (1987). The MK test is a non-parametric method for detecting trends in time series and involves the calculation of the *S* statistic which takes negative (positive) values for negative (positive) trends and the *Z* statistic, used to derive the *p*-value.

3. Climate Impact Drivers (CIDs)

Climate Impact Drivers (CIDs) are physical climate system conditions (e.g. means, events, extremes) that affect an element of society or ecosystems and are thus a priority for climate information provision. Depending on system tolerance, CIDs and their changes can be detrimental, beneficial, neutral or a mixture of each across interacting system elements, regions and society sectors. Each sector is affected by multiple CIDs and each CID affects multiple sectors. A CID can be measured by indices to represent related tolerance thresholds. (IPCC-AR6-WG1, 2021, p. 1770)

The latest IPCC AR6 process led to the development of 7 CID types (heat and cold, wet and dry, wind, snow and ice, coastal, open ocean, and other) and 33 distinct CID categories (CID, 2022): they are summarised in Table 12.12 (IPCC-AR6-WG1, 2021, p. 1856) which also presents CID emergence in different time periods based on multiple methods as provided by recent literature.

As shown in Table 12.12, most of the CIDs do not exhibit significant changes before the end of the XXI century even in the most pessimistic RCP8.5 scenario. It is important to note that the RCP8.5 scenario does not represent a typical 'business-as-usual' projection but serves instead as a high-end, high-risk scenario while the RCP4.5 scenario is approximately in line with the upper end of aggregate NDCs (Nationally Determined Contributions) emissions levels (Hausfather & Peters, 2020; IPCC-AR6-WG1, 2021, p. 250; IPCC-AR6-WG3, 2022, p. 317) as also confirmed by a recent JRC report (Keramidas et al., 2025): our analysis will thus focus on the observation of CIDs time series and not on future scenarios.

As shown by EM-DAT, most climate related disasters originate from floods and tropical cyclones (EMDATdcs, 2025). They lead to death, injury, loss of livelihoods and displacement and place a huge burden on societies, economies and the environment. Specific considerations will then be dedicated to these phenomena.

3.1. Floods

Floods are among the most significant natural disasters in terms of affected people. The extent to which a flood causes impacts is determined not only by the magnitude of the flood, but also by human and societal choices related to infrastructures, citizens preparedness, effectiveness of the civil protection organisation and other factors (Lowe et al., 2013).

Data on flooded soils at a global level are also important in terms of greenhouse gas emissions because water-saturated soils emit methane and soils with water excess but not completely saturated emit nitrous oxide, both important greenhouse gases. The amount of these emissions is a function of temperature and at medium-high latitudes the impact is greater during the summer (Luo et al., 2013).

The evidence on floods reported by IPCC is: '*low confidence in the emergence of heavy precipitation and pluvial and river flood frequency in observations, despite trends that have been found in a few regions*' (IPCC-AR6-WG1, 2021, p. 1854). We are also reminded about the difficulty in analysing the temporal trend of floods and relating it to climate change (IPCC-AR6-WG1, 2021, p. 1086).

Regarding river floods specifically, the following assessment is provided:

Peak flow trends are characterized by high regional variability and lack overall statistical significance of a decrease or an increase over the globe as a whole. Of more than 3500 streamflow stations in the USA, central and Northern Europe, Africa, Brazil, and Australia, 7.1% stations showed a significant increase, and 11.9% stations showed a significant decrease in annual maximum peak flow during 1961–2005'. Furthermore: 'In summary there is low confidence in the human influence on the changes in high river flows on the global scale. In general, there is low confidence in attributing changes in the probability or magnitude of flood events to human influence because of a limited number of studies, differences in the results of these studies and large modelling uncertainties. (IPCC-AR6-WG1, 2021, p. 1569)

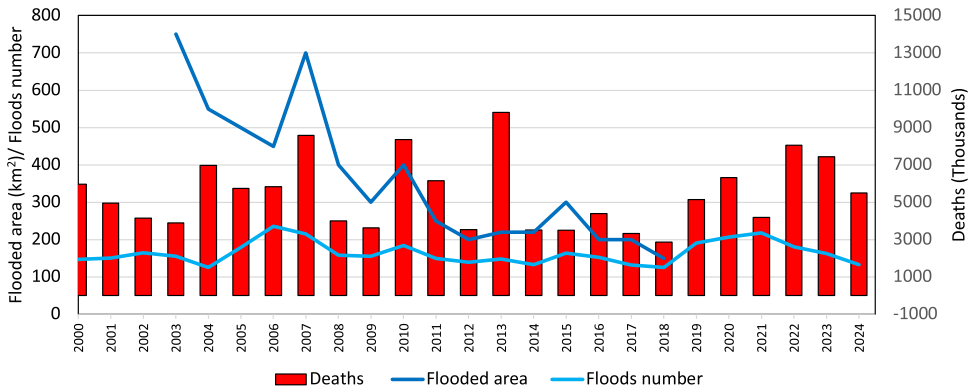


Figure 2. Estimated annual inundated area (Joshi et al., 2024) and number of flood disaster events (EMDAT, 1988) left axis; deaths from flooding (EMDAT, 1988) right axis.

A recent study (Joshi et al., 2024) is reporting a decrease in estimated annual global flooded area between 2003 and 2018, consistent with numbers of flood disasters and deaths from EMDAT, as shown in Figure 2: note both the reduction in flooded area estimates and the Mann-Kendall (MK) test indicating no statistically significant trend in flood-related deaths, as shown in Table 1.

On a more limited scale, detailed data on flood events in Italy with at least one death or missing person are trusted to be robust and complete since 1951 by the database coordinators (CNR-IRPI, 1937). In Figure 3 the 1951-2024 time series of 'Yearly deadly flood Events' is shown: the MK trend analysis shows the absence of statistically significant trend, as reported in Table 1.

3.2. Tropical and mid latitude cyclones

Historically, around 60% of all economic damages caused by disasters worldwide have resulted from hurricanes in the United States (Mohleji & Pielke Jr, 2014), with more than 80% of this damage attributable to major hurricanes.

Global observations do not show any statistically significant trend in either the number of hurricanes or their accumulated energy, as shown in Figure 4 and confirmed by several region-specific studies. For instance, no significant trends are detected for the United States even over a dataset spanning more than 160 years (Loehle & Staehling, 2020), nor for other global regions (Diamond & Schreck, 2021; Xiang et al., 2020), findings that are also reflected in Table 12.12 of the IPCC AR6 report (IPCC-AR6-WG1, 2021, p. 1856).

A recent study analysing the destructive potential of tropical cyclones (Tu et al., 2024) reveals no clear global trend in most ocean basins. However, a statistically significant decrease in the power dissipation index has been recorded in the South Indian Ocean basin since 1994. This trend appears to be largely due to a decline in both the frequency and duration of tropical cyclones in that region (see Figure 5).

An additional parameter relevant to tropical cyclone (TC) impacts is their translation speed, defined as the speed at which cyclones move across the Earth's surface. This variable has a direct influence on local rainfall totals, as slower-moving cyclones tend to release more rainfall over a specific area. According to the IPCC, 'TC translation speed



Table 1. Climate indicators: in green physical-environmental, in blue socio-economic and in red health indicators are shown. The colour in the last column corresponds to the statistically significant trend.

Indicator (units)	Source	Increasing trend			
		Period	Mk-S	Mk-Z	Mk-P
Physical-environmental					
CO2 atmospheric level (ppmv)	(NOAA-GML, n.d.)	1959-2024	2145	11.865	1.7965E-32
Cyclones – Tropical – All Hurricanes (events)	Colorado Univ & NOAA	1980-2024	-99	-0.96166	0.33622
Cyclones – Tropical – Cat. 3+ Hurricanes (events)	Colorado Univ & NOAA	1980-2024	189	1.849	0.064452
Cyclones – Tropical – Named Storms (events)	Colorado Univ & NOAA	1980-2024	91	0.88132	0.37814
Cyclones – Tropical Cyclones Energy (ACE)	Colorado Univ & NOAA	1980-2024	-51	-0.48914	0.62474
Drought (disasters number)	CRED EMDAT	2000-2024	41	0.93787	0.34831
Drought – water deficit (10 ^{^6} m3)	(Willmott & Matsuura, 2001)	1951-2017	1261	6.8185	9.20E-12
Drought – Vegetation Health Index VHI (0-100)	(NOAA-STAR, 2024)	1982-2023	-97	-1.0404	0.29816
Explosive Cycl. in North Emisph. Mid latitude oceans (events)	(Fu et al., 2020)	1979-2016	-34	-0.41556	0.67773
Explosive Cycl. in Mediterranean (events)	(Carniel et al., 2024)	1979-2020	-43	-0.46867	0.63931
Explosive Cycl. in Mediterranean (intensity, Bergeron units)	(Carniel et al., 2024)	1979-2020	39	0.41213	0.68025
Floods (disasters number)	CRED EMDAT	2000-2024	1	0	1
Floods (area, 10 ^{^3} km2)	(Joshi et al., 2024)	2002-2018	-98	-4.0277	5.6324E-05
Floods Italy (events)	(CNR-IRPI, 1937)	1951-2024	-35	-0.15909	0.87359
Ice Arctic Volume (10 ^{^3} km3)	(Piomas, 1979)	1979-2024	-848	-8.0199	1.0585E-15
Leaf Area Index (Global Mean Anomaly)	(Chen et al., 2024)	2001-2020	161	5.1993	2.0004E-07
Meteo + Climate + Hydro (disasters number)	CRED EMDAT	2000-2024	58	1.3329	0.18255
Precipitation – Global Mean value (anomaly)	(Dunn et al., 2020)	1951-2018	864	4.5759	4.7407E-06
Global Temperature Anomaly at Surface (°C)	(Hadcrut5, 2025)	1951-2024	2060	9.6089	7.3318E-22
Temperature, extreme (disasters number)	CRED EMDAT	2000-2024	-61	-1.4042	0.16025
Wildfire (disasters number)	CRED EMDAT	2000-2024	19	0.42227	0.67282
Wildfires – burned area (ha)	GWIS	2002-2023	-153	-4.2861	1.8185E-05
Wildfires (number)	GWIS	2002-2024	-147	-4.1169	3.8401E-05
Socio-economic					
Drought – Economic damage (Share of GDP)	(OWD-WB-EMDAT, 2024)	2000-2022	57	1.479	0.13914
Floods – Economic damage (Share of GDP)	(OWD-WB-EMDAT, 2024)	2000-2022	7	0.15846	0.87409
GDP – Gross Dom. Prod. (Trillion US \$\$ 2023)	World Bank	1960-2023	1990	11.524	1.0043E-30
Harvest data – global harvested dry matter, 156 crops (10 ^{^9} t)	FAOSTAT	1961-2022	1912	11.335	8.8122E-30

Harvest data – yields of the 4 main crops (t/ha)	FAOSTAT	1961-2023	1883	11.163	6.2075E-29
Prosperity Index – Prosperity Gap*	World Bank	1981-2024	-922	-9.3152	1.2168E-20
Prosperity Index – Population Below Poverty Line**	World Bank	1981-2022	-825	-8.93	4.2597E-19
Temperature, extr. – Economic damage (Share of GDP)	(OWD-WB-EMDAT, 2024)	2000-2022	-37	-0.97321	0.33045
Wet mass movement – Economic damage (Share of GDP)	(OWD-WB-EMDAT, 2024)	2000-2022	-14	-0.34678	0.72876
Wildfires – Economic damage (Share of GDP)	(OWD-WB-EMDAT, 2024)	2000-2022	57	1.479	0.13914
Health					
Cyclones – Tropical Cyclones (Deaths)	CRED EMDAT	2000-2024	-30	-0.67729	0.49822
Disability (Daly rate age standardised)	(GBD 2019 Diseases and Injuries Collaborators, 2020)	1990-2019	-431	-7.6716	1.6981E-14
Floods (deaths)	CRED EMDAT	2000-2024	-46	-1.051	0.29327
Floods Italy (Deaths)	CNR IRPI	1951-2024	-169	-0.78506	0.43242
Malaria (Death rate)	(GBD, 2022)	1980-2021	-503	-5.4425	5.2538E-08
Meteo + Climate + Hydro disasters (Deaths)	CRED EMDAT	2000-2024	-12	-0.2569	0.79725
Outdoor ozone pollution (Death rate)	(IHME, 2024)	1990-2021	-231	-3.755	0.00017331
Outdoor Particulate Matter (Death rate)	(IHME, 2024)	1990-2021	-272	-4.4012	1.0764E-05
Temperature, extreme (Death rate)	(GBD, 2022)	1980-2021	-363	-3.9262	8.6295E-05
Unsafe water (Death rate)	(IHME, 2024)	1990-2021	-496	-8.0271	9.98E-16

*Prosperity gap: average factor by which incomes must be multiplied to reach the \$25 standard for every member of that society

**Population below poverty line: poverty headcount ratio at \$2.15 a day (2017 PPP) (% of population)

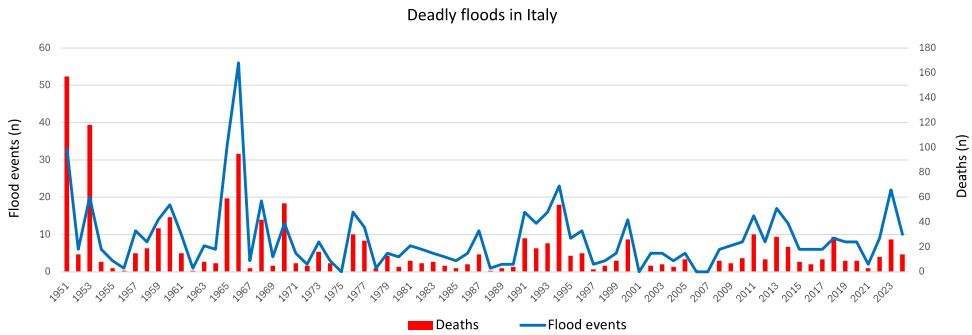


Figure 3. Number of flood events in Italy with at least one death or missing person since 1951 (CNR-IRPI, 1937).

has likely slowed over the conterminous USA since 1900. Evidence of similar trends in other regions is not robust.’ (IPCC-AR6-WG1, 2021, p. 1519).

These apparent slowing trends may, however, be largely attributable to data heterogeneity. Some studies suggest that meridional shifts in cyclone tracks – possibly an artifact of new satellite-era observational techniques – have influenced these results (IPCC-AR6-WG1, 2021, p. 1587).

Accordingly, IPCC reports that ‘There is presently no clear consensus in projected changes in TC translation speed, although recent studies suggest a slowdown outside of the tropics, but regionally there can even be an acceleration of the storms’ (IPCC-AR6-WG1, 2021, p. 1591).

More recent literature further highlights the challenge of non-homogeneous data records, especially in relation to precipitation: ‘Estimates of TC-associated precipitation in the period before the 2000s should be treated with care, as they might be affected by non-stationarity in the amount and quality of assimilated precipitation data’ (Scocimarro et al., 2024). Additionally, in some ocean basins, an interdecadal rhythm in TC activity has been observed for the period 1977–2020 (Shan et al., 2023).

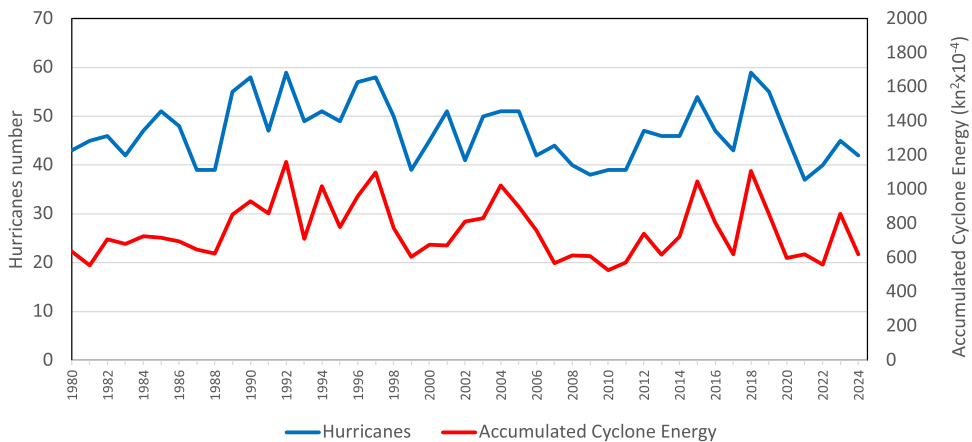


Figure 4. Global Hurricane Frequency – 12-month running sums. The top time series is the number of global tropical cyclones that reached at least hurricane-force (maximum lifetime wind speed exceeds 64-knots). The bottom time series is the Accumulated Cyclone Energy (ColState, 2020).

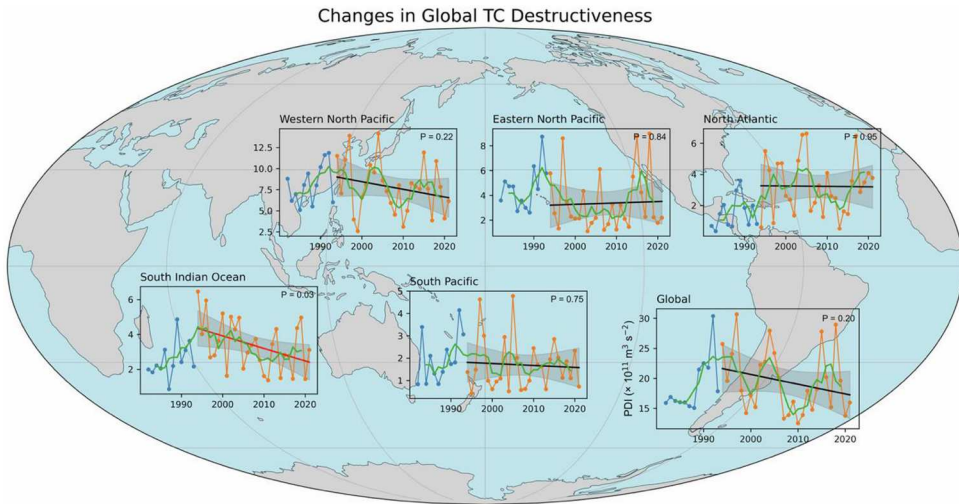


Figure 5. Time series of the cumulative power dissipation index (PDI) of tropical cyclones (TCs) for each basin and the global. Shaded areas are the two-sided interval of the linear trend at the 95% confidence level; the solid line (red is significant) represents the linear regression since the mid-1990s. The green curve represents the 5-year running average distributions of the PDI (Tu et al., 2024).

Explosive cyclones (ECs) are characteristic of the mid-latitude oceans and belong to the broader category of extratropical cyclones, defined by the American Meteorological Society (AMS) as: ‘any cyclonic-scale (wavelength of 1000–4000 km) storm that is not a tropical cyclone, usually referring only to the migratory frontal cyclones of middle and high latitudes.’ (AMS, 2024). While ECs are relatively rare, on average, 1 in every 50 extratropical cyclones, they are potentially highly destructive. Typically occurring in winter, ECs have a life cycle of 2–5 days and a horizontal scale of approximately 2000–3000 km (Zhang et al., 2017; Zhang et al., 2021). Their impacts can be substantial due to intense winds and torrential rainfall, often resulting in extensive property damage and loss of life.

As with tropical cyclones, the climatology of ECs can be characterised in terms of their frequency and intensity. A foundational climatology for the North Atlantic and North Pacific Oceans was provided by Fu et al. (2020), covering the period 1979–2016.

In the Mediterranean region, which is densely populated and historically prone to such events, a seminal study by Conte (1986) first presented a climatology of ECs. More recently, an updated assessment of EC events and their energy distribution has been proposed by Carniel et al. (2024), with key metrics summarised in Table 1.

4. Response indicators (RINDs)

The number of natural disasters caused by weather-related events (e.g. hurricanes, floods, droughts, wildfires, wet mass movements, storms) can be used as a preliminary climate response indicator.

The number of recorded Meteo-Hydro-Climatology disaster events and related deaths since 2000 is shown in Figure 6 and no clear trend is found by the MK trend analysis, as reported in Table 1.

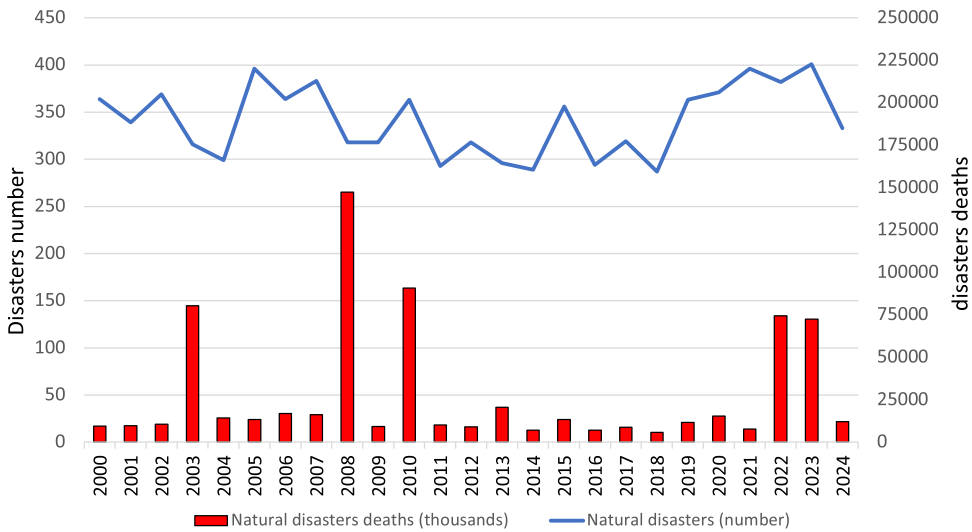


Figure 6. Number of recorded natural Meteo-Hydro-Climate disaster events and deaths since 2000

The IPCC has carried out specific work concerning climate impact indicators and we followed the IPCC definitions and aggregations of impacts in analysing RINDs: *'changes in climate-related systems here refer to any long-term trend, irrespective of the underlying causes; thus, an observed impact is not necessarily an observed impact of anthropogenic climate forcing'*.(IPCC-AR6-WG2, 2022, p. 2423). To keep the main text concise and focused, the analysis of some RINDs (air pollution, coastal systems and social conflicts) has been moved to Supplementary Material Appendix 2.

4.1. Global trend in diseases and injuries

A study of the Global Burden of Diseases, Injuries, and Risk Factors (GBD) was conducted for 369 diseases and injuries across 204 countries and territories for the period 1990–2019 using age-standardised DALY index (GBD 2019 Diseases and Injuries Collaborators, 2020). DALY is the sum of the years of life lost to due to premature mortality (YLLs) and the years lived with a disability (YLDs) due to prevalent cases of the disease or health condition in a population with a given life expectancy. The number of global DALYs remained almost constant on the reference period, but after accounting for population growth and ageing by converting counts to age-standardised rates, there were clear improvements in overall health (Figure 7). More specifically, over the decade 2010–2019, the pace of decline in global age-standardised DALY rates accelerated in age groups younger than 50 years compared with the 1990–2009 time period. The annualised rate of decline was greatest in the 0–9-year age group while the rate of change for those aged 50 years and older was slower from 2010 to 2019 compared with the earlier time period.

4.1.1. Waterborne diseases

A review of WBDs and their links to climate variability and change is proposed by Semenza and Ko (2023). IPCC AR6 states that evidence on the impact of long-term

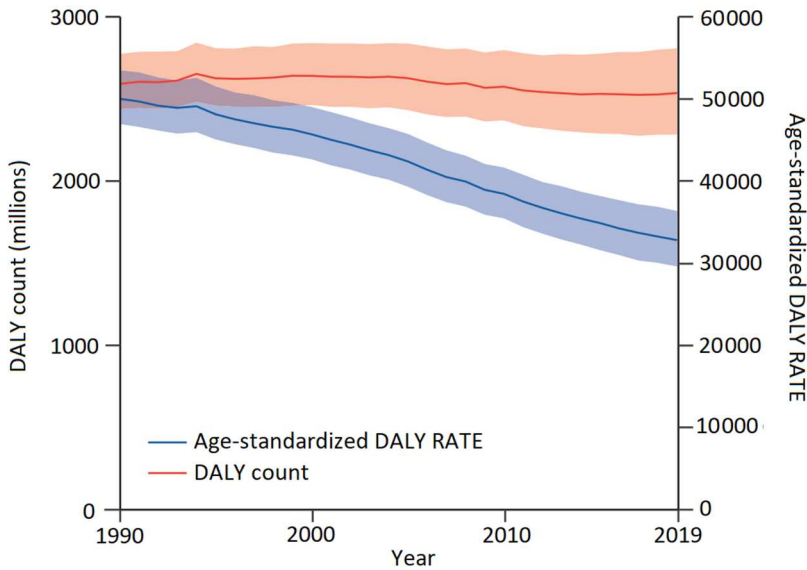


Figure 7. Global DALYs and age-standardised DALY rates, 1990–2019 Shaded sections indicate 95% uncertainty intervals. DALY = disability-adjusted life-year. Image from (GBD 2019 Diseases and Injuries Collaborators, 2020).

climate change on waterborne diseases is largely lacking (O’Neill et al., 2022). Therefore, an index based on WBDs is not suitable for capturing the effects of climate change.

Morbidity and mortality from WBDs are strictly related to poor water quality which is an essential factor for the spread of water borne diseases. An illustrative case study is given by diarrhoeal diseases that in children under five were the second leading cause of death in 2019. Liu et al. (2024) highlights that diarrhoeal rate in children under five declined globally by 4.84% annually from 2000 to 2021 and the decline was stronger (–5.10%) in low socio-demographic index (SDI) regions, where it was positively correlated with improved water services. A more moderate decline of 2.03% was highlighted in high SDI regions.

Figure 8 shows the significant death rate decrease from unsafe water sources since 1990: the gap between low and high income countries is evident and this underlines the importance of dedicated and targeted investments to mitigate possible climate change impacts.

4.1.2. Vector-borne diseases

Vector-borne diseases (VBDs) account for more than 17% of all infectious diseases (World Health Organization, 2024) and one-sixth of the world’s infection-associated DALY.¹ Main VBDs in growing order of mortality are dengue, with 6000 deaths in 2023 (ECDPC, 2024), leishmaniasis with 20,000–40,000 deaths (Alvar et al., 2012), schistosomiasis with 200,000 yearly deaths (Verjee, 2019) and malaria, that is by far the most important VBD with nearly half of the world’s population at infection risk and 608,000 deaths in 2022, 95% of them in Africa (CDC, 2022). The global relevance of the problem pushes us to mainly focus our attention on malaria.

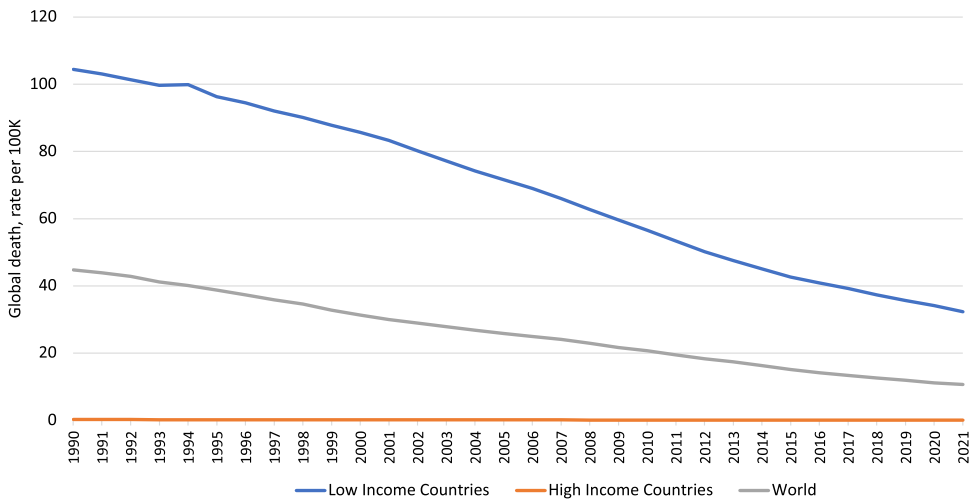


Figure 8. Unsafe Water Sources global death, rate per 100000 people. The number of deaths due to cause divided by the mid-year population (OWD-UWS, 2025).

The role of climate variability and change in WBDs spread is complex due to the interactions with other causal factors like international travel and trade, land use changes, urbanisation and sanitary and economic conditions. If travel and trade enhance the spread of vectors and hosts, urbanisation promotes the emergence of diseases transmitted by vectors adapted to urban environment while the requirement for clear water for the breeding site of *Anopheles* mosquito is believed to be a major factor able to reduce the development of anopheline larvae in urban settings (Baker et al., 2022; Rossati et al., 2016).

Climate affects many VBDs acting on pathogens, vectors and hosts: temperature growth may shift the spatial range of malaria vectors (*Anopheles* spp.) and some viruses (*Aedes* spp.) to higher latitudes and altitudes, while temperature increase in tropical regions might be unfavourable to the survival of the same vector (Nakase et al., 2024; Rossati et al., 2016). Water availability in ephemeral pools during rainy periods creates a breeding habitat for mosquitoes while dry periods and urban areas decrease lifespan of mosquito vectors such as *Aedes* (Nakase et al., 2024) and *Anopheles* (Santos-Vega et al., 2022).

The genus *Anopheles* is widespread from high latitudes to the equator: the *Anopheles maculipennis* complex was responsible for most of the malaria transmission in EU countries where malaria was endemic until the 1970s: it is documented from the Mediterranean southern shore up to the polar circle (Gelabert et al., 2017), while the tropical species *Anopheles gambiae* today causes the greatest concern in sub-Saharan Africa, where >90% of malaria cases and mortality have been reported (World Health Organization, 2021). Its development is most efficient at 28–32°C, while survival is optimal between 20–30°C (Bayoh & Lindsay, 2003). Rising global temperatures could expand colonisable areas by warming previously unsuitable regions and rendering others too hot for survival. Additionally, human-induced increases in marshy areas or floods may contribute to malaria spread, though the IPCC AR6 reports low confidence in global trends regarding flood frequency or magnitude (see par. 3.1). A recent study predicts a net decrease in areas suitable for malaria transmission from 2025 onward (Smith et al., 2024).

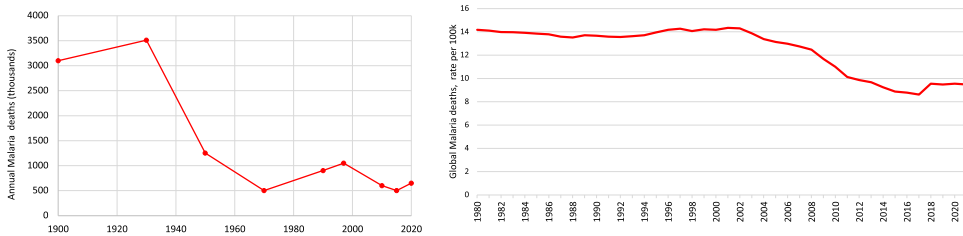


Figure 9. Global estimated number of malaria deaths (Carballar-Lejarazú et al., 2023) on the left; global death rate per 100 K (GBD, 2022). The number of deaths due to cause divided by the mid-year population.

Human interventions loom larger than climate change as testified in the twentieth century by the decrease in malaria endemicity and mortality in the face of rising global temperatures. Gething (Gething et al., 2010) showed a global decrease in malaria endemicity from 58% of the world surface in 1900 to 30% by 2007 and Carballar-Lejarazú et al. (2023) showed a significant mortality decline from 1920 to 1970, with a fluctuating trend afterwards (Figure 9). These time series show a substantial correlation weakening between climate and malaria endemicity (Gething et al., 2010): this reduction is mainly driven by land management, health systems and socio-economic conditions as highlighted by the approach to malaria in Europe (Climate Adapt, 2022), once largely affected by this disease (Reiter, 2008).

Malaria eradication in the twentieth century was driven by improved living conditions, environmental sanitation, access to drugs, and border stability. Conversely, malaria reintroduction in malaria-free countries has often resulted from political instability, reduced funding for vector control, and migratory flows from endemic areas. However, the widespread use of mosquito nets and effective antimalarial drugs has significantly reduced malaria cases and mortality (Rossati et al., 2016).

4.2. Temperature-related mortality

It is well established that extreme temperatures cause excess mortality in human populations. Heat kills by overheating the body and giving rise to pathologies such as cardiovascular or kidney disease, respiratory infections and diabetes. Cold kills because the body reduces the flow of blood to the epidermis, increases blood pressure and lowers immune defences. Both for heat and cold, the most vulnerable categories of society – the elderly and the weakest – are most at risk (Ritchie, 2024).

Global mortality from extreme thermal events is clearly more marked for cold than for heat. Gasparrini et al. (2015), using data from 384 locations in several countries estimated that 7.7% of the deaths from all causes was attributed to temperatures and found that 7.3% were from cold and 0.4% from heat. Gasparrini concluded that

Most of the temperature-related mortality burden was attributable to the contribution of cold. The effect of days of extreme temperature was substantially less than that attributable to milder but non-optimum weather. This evidence has important implications for the planning of public-health interventions to minimise the health consequences of adverse temperatures, and for predictions of future effect in climate-change scenarios. (Gasparrini et al., 2015)

More recently, Zhao et al. (2021) examined mortality and ambient temperature 2000-2019 time series from 750 locations in 43 countries, where global temperatures increased by 0.26 °C per decade: 6,826,550 deaths per year (9.4% of the deaths from all causes) were associated with suboptimal temperatures, 91% of which (8.5% of the deaths from all causes) were caused by cold, while only 9% (0.9% of the deaths from all causes) were caused by heat. Globally, between 2000-03 and 2016-19, the excess mortality rate associated with cold decreased by 0.51% while that associated with heat increased by 0.21%, leading to a net decline of 0.30%.

The conclusions of Gasparrini et al. (2015), and Zhao et al. (2021) are in agreement with IPCC AR6 (IPCC-AR6-WG2, 2022, p. 2426):

heat-attributable mortality fractions have declined over time in most countries owing to general improvements in health care systems, increasing presence of heating and air conditioning systems, and behavioural changes. These factors, which determine the susceptibility of the population to heat and cold, have predominated over the influence of temperature change.

Overall, heat and cold adaptation activities in human populations reduce susceptibility and result in significant reductions in mortality.

4.3. Food system

Life on Earth is based on carbon, which is subject to a very complex cycle where atmospheric CO₂ is a fundamental segment as a key ingredient in photosynthesis (Prajapati et al., 2023); this process is modulated by abiotic and biotic limitations (e.g. temperature, soil water content, hail, frost, parasites, pathogens, weeds and so on) that strongly affect the final production of crops (Mariani, 2017). Each limitation interacts with each other: for example, good soil water availability counteracts the negative effects of heat waves, allowing thermoregulation of plants through stomatal transpiration. Conversely, higher atmospheric CO₂ concentrations allow plants to reduce water losses per unit of carbon gain by reducing stomatal conductance when the CO₂ gradient between the atmosphere and the leaf interior increases, as stated by Swann et al. (2016). These authors also stated that the effect of decreasing stomatal conductance prevails over the increase of evapotranspiration due to the increase in leaf area determined by better carbon nutrition.

For decades, agriculture and livestock breeding have undergone strong technological advancements, driven by science-driven improvements in genetic, breeding and cropping techniques. In the specific case of crops, this has determined a general increase in crop yields, enhanced also by CO₂ growing atmospheric levels (Ritchie, 2024). Increase in crop yields is shown by Faostat (FAO, 2024) which reports world time series of 156 different crops, showing a global dry weight production growth from 1,25 Gt in 1961 to 5,06 Gt in 2023 (+305%).

Restricting the Faostat dataset analysis to the four main crops (maize, rice, wheat and soybeans that satisfy 64% and 50% of the global calorie and protein mankind requirements) it is possible to observe that global yields from 1961 to 2023 show a regular increase of +381% and there are no signs of growing negative events (Alimonti & Mariani, 2023) as shown in Figure 10. Conversely, IPCC AR6 (IPCC-AR6-WG2, 2022, p. 724) states that '*climate change has caused regionally different, but mostly negative, impacts on crop yields and quality and marketability of products*' and reports a vast

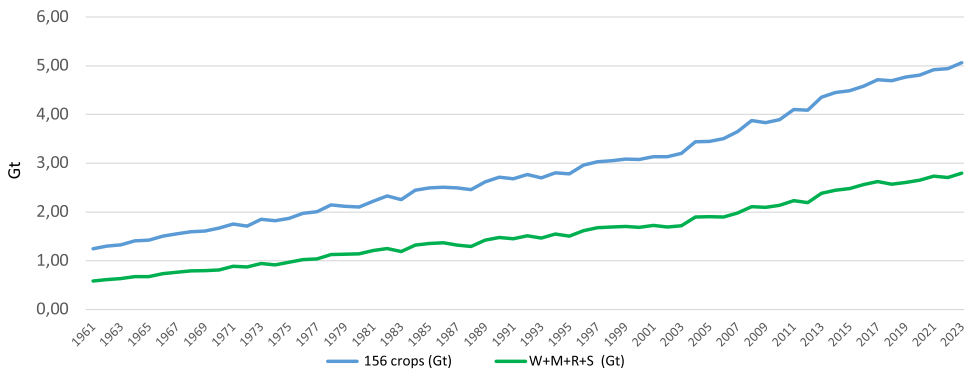


Figure 10. Global dry weight harvested for the full set of 156 crops gathered in the Faostat dataset and for wheat, maize, rice and soybeans (our elaborations on Faostat data FAO, 2024).

collection of references on climate change negative effects (IPCC-AR6-WG2, 2022, p. 728). It is also reported that ‘*One global study using an empirical model estimated the negative effect of anthropogenic warming trends from 1961 to 2017 to be on average 5.3% for three staple crops (5.9% for maize, 4.9% for wheat and 4.2% for rice)*’ (IPCC-AR6-WG2, 2022, p. 724). We underline that these negative effects are too modest if compared to the 305% (or +381% if restricted to the 4 main crops) increase in dry matter yields highlighted by FAOSTAT and reported also by IPCC AR6 (IPCC-AR6-WG2, 2022, p. 728):

Global yields of major crops per unit land area have increased 2.5- to 3-fold since 1960. Plant breeding, fertilisation, irrigation and integrated pest management have been the major drivers, but many studies have found significant impacts from recent climate trends on crop yield.

In our view it is essential that the ‘*regionally different, but mostly negative, impacts*’ of climate change on global food production stated in IPCC AR6 are reconciled with the global steady growth highlighted by FAOSTAT. This can be achieved by adopting the scale perspective defined by Adam Smith’s empirical rule (Smith, 1776), stating that in a large corn-producing region with free trade and communication, unfavourable seasons like drought or excessive rain rarely cause famine because losses in one area are often offset by gains in another.

Consider that the Smith’s rule underling the extraordinary link among agriculture, trade and communication routes, is also recognised by IPCC AR6 (IPCC-AR6-WG2, 2022, p. 2426):

due to complex interactions with socioeconomic conditions climate induced trends in crop yields and productions do not directly transmit to crop prices, availability of food or nutrition status. This complexity, in addition to the limited availability of long-term data, has so far impeded the detection and attribution of a long-term impact of climate change on associated food security indicators.

In light of all this, we propose to use the crop global dry matter production deduced from data recorded in the FAOSTAT dataset and shown in Figure 10 as an indicator of global agricultural production. These data could be integrated, if necessary, with global production data collected by USDA, used to produce world monthly reports (USDA, 2024).

4.4. River flooding and reduction in water availability

River floods are one of the most common natural hazards, causing devastating impacts worldwide. Furthermore, climate change may increase the frequency or magnitude of flooding. The impact of flooding is particularly severe in developing countries due to low levels of flood protection.

This subject was already introduced in a paragraph 3.1 but we believe it deserves further attention since it has been specifically addressed by IPCC among the observed impacts with a trend that, as shown below, is not consistent with data and observations.

From IPCC AR6 (IPCC-AR6-WG2, 2022, p. 2425) it can be read:

On the global scale, the spatial pattern of observed trends is largely explained by observed changes in climate conditions as demonstrated by multi-model hydrological simulations forced by observed weather, while the considered direct human influences play only a minor role on global scale. The annual total number of reported fatalities from flooding shows a positive trend ($1.5\% \text{ yr}^{-1}$ from 1960 to 2013, (Tanoue et al., 2016)) which appears to be primarily driven by changes in exposure dampened by a reduction in vulnerability, while climate-induced increases in affected areas show only a weak positive trend on the global scale.

However we believe this statement results from a partial reading of the referenced article by Tanoue where flood disaster statistics come from EM-DAT. As discussed at the beginning of the 'Data and Methods' paragraph, EM-DAT disasters trend is affected by a 'better reporting' bias and excluding pre-2000 data from trend analyses based on EM-DAT is strongly recommended (EMDATsb, 2025).

Tanoue et al. are well aware of such a limitation and they write:

However, many events that meet the criteria are often not recorded in the EM-DAT. For example, the number of countries in which flood events were reported in the EM-DAT was less than 50 until the mid-1980s, reaching around 80 after 2000. ... this indicates that one of the main drivers of the increased number of flood reports is improvements in data accessibility and information gathering. (Tanoue et al., 2016)

In the conclusions of their study, we can read: 'global mortality rates and global loss rates showed a decreasing trend, and inverse relationships were found between flood vulnerability and GDP per capita, indicating an improvement in flood vulnerability at the global scale since 1960 associated with economic growth' (Tanoue et al., 2016). This is in agreement with the 'Low confidence in the direction of change' statement on floods by IPCC, with the decrease of flooded area shown by satellite data reported in the paragraph 3.1 and with the EM-DAT data summarised in Table 1.

4.4.1. Water availability and drought

According to the American Meteorological Society (AMS, 2019), drought is defined as 'a period of abnormally dry weather long enough to cause a serious hydrological imbalance.' This definition emphasises the prolonged duration and impact on the water cycle, rather than merely a lack of rainfall, highlighting the importance of drought metrics for classifying drought into five main categories (meteorological, agricultural, ecological, hydrological, and socio-economic) (National Drought Mitigation Center, 2025). These metrics are used to quantify drought severity, location, timing and duration, as well as its impact on various socio-economic sectors (domestic, agriculture, industry,

transport, tourism, healthcare, etc.). The metrics include various indicators such as precipitation, evapotranspiration, temperature, streamflow, soil water content and water deficit, snowpack, and remotely sensed indices referred to plant canopies such as the Normalised Difference Vegetation Index (NDVI) and the Vegetation Health Index (VHI).

Concerning droughts, from IPCC AR6 (IPCC-AR6-WG2, 2022, p. 2425) we can read:

Although anthropogenic climate forcing has increased droughts intensity or probability in many regions of the world (medium confidence), the existing knowledge has not yet been systematically linked to attribute long-term trends in malnutrition, fatalities and damages induced by reduced water availability to anthropogenic climate forcing or long-term climate change.

We also recall that from IPCC WGI Table 12.12 (IPCC-AR6-WG1, 2021, p. 1856), concerning Hydrological, Agricultural and Ecological drought it is reported '*Low confidence in the direction of change*'.

Again, from IPCC AR6 (IPCC-AR6-WG1, 2021, p. 1854), it can be read

There is low confidence in the emergence of drought frequency in observations, for any type of drought, in all regions. Even though significant drought trends are observed in several regions with at least medium confidence, agricultural and ecological drought indices have interannual variability that dominates trends, as can be seen from their time series (medium confidence).

About drought onset triggered by precipitation deficit, AR6 states that the central role is attributed to atmospheric circulation at different scales: '*There is high confidence that atmospheric dynamics, which vary on interannual, decadal and longer time scales, is the dominant contributor to variations in precipitation deficits in the majority of world regions*'; moreover: '*There is low confidence in the effects of greenhouse gas forcing on changes in atmospheric dynamic and on associated changes in drought occurrence*' (IPCC-AR6-WG1, 2021, p. 1570).

Given the importance of droughts for food security and water supply across various socioeconomic sectors, an approach based on three indices has been adopted and is summarised in [Table 1](#):

- the number of global drought disasters reported by EM-DAT ([Figure 11](#));
- the global water deficit, defined as the atmospheric evapotranspiration demand that vegetation cannot meet due to insufficient soil moisture (Willmott, 1977);
- the global mean value of the Vegetation Health Index (VHI) applied to natural and cultivated vegetation.

The VHI is a combined moisture-thermal index, based on the Vegetation Condition Index (VCI), which accounts for moisture-related vegetation health, and the Temperature Condition Index (TCI), which accounts for thermal-related vegetation health (Kogan et al., 2020). Satellite-derived VHI allows for global coverage of natural and cultivated vegetation with suitable pixel resolution, avoiding the issues associated with limited weather station data collection. Kogan et al. (2020) analysed global crop VHI values for the period 1981–2018, showing that for the globe as a whole, hemispheres, and major grain-producing countries (China, USA, and India), drought has neither intensified nor expanded over these 38 years, despite a strong increase in the global temperature

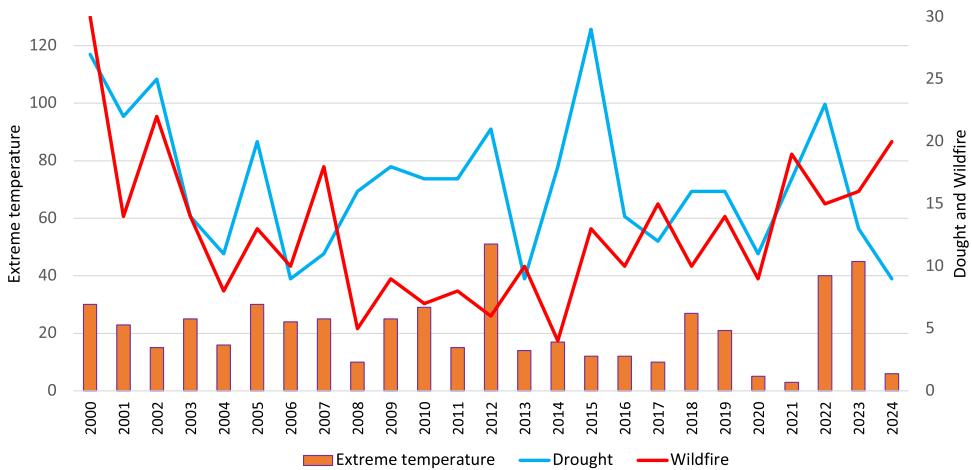


Figure 11. Number of recorded EM-DAT disasters originated by drought, extreme temperature and wildfire.

anomaly. The authors therefore concluded that food security in the coming years is likely to remain at the level observed in the most recent decade.

A recent paper by Vicente-Serrano et al. (2022) reviewed the scientific literature on droughts and analysed meteorological drought trends using long-term precipitation records and various drought metrics to evaluate the role of global warming in trends of agricultural, hydrological, and ecological drought severity over the last four decades – a period during which a sharp increase in atmospheric evaporative demand (AED) has been recorded. The results show that meteorological droughts have not exhibited substantial changes at the global scale over the past 120 years. Conversely, the observed increase in drought severity over recent decades appears to be primarily linked to the significant rise in AED during the same period, with important implications for agricultural and ecological droughts. Vicente-Serrano et al. (2022) also demonstrate that increases in the frequency and severity of hydrological droughts can partly be attributed to human activities such as agricultural intensification. In this context, assuming the stationarity of crop water use efficiency (kg of water per kg of product), it can be inferred that the 136% increase in global crop yields observed from 1961 to 2020 (Fuglie et al., 2024) has corresponded to a proportional increase in water consumption.

4.5. Economic impacts

Extreme weather events such as tropical cyclones, droughts, and severe fluvial floods not only cause substantial immediate direct economic damage but also reduce economic growth in the short term (year of, and year after event) as well as in the long term (up to 10–15 years after event). (IPCC-AR6-WG2, 2022, p. 2427)

Nevertheless, these events, as also summarised in Table 12.12 (IPCC-AR6-WG1, 2021, p. 1856) do not currently show any trend resulting from climate change.

Scientific literature finds little evidence to support claims that any part of the increase in global economic losses is attributable to human-caused changes in climate (Klotzbach et al., 2018; McAneney et al., 2019; Pielke, 2021; Pielke et al., 2008; Pielke & Landsea, 1998)

and such findings have been recently confirmed by more specific studies focusing on US territory that show that economic damages caused by such events, normalised by the potentially damageable GDP, show a constant or decreasing trend in recent years (Pielke, 2024).

As underlined by IPCC, going beyond extreme weather events, economic production depends nonlinearly on temperature: it increases below a threshold but decreases above it. Over the past 50 years, climate change has slowed global GDP growth, with developing countries suffering more and colder industrialised nations sometimes benefiting. Between-country inequality has decreased but it has increased compared to a no-climate-change scenario (IPCC-AR6-WG2, 2022, p. 2427).

Several studies try to quantify the overall effect of climate change on GDP and there is a general agreement on a few % expected loss by the end of the twenty-first century depending on the model and on the projected temperature increase (Diaz & Moore, 2017; Nordhaus & Moffat, 2017; Tol, 2024) to be compared with a much more projected per capita GDP increase by the end of the century (Lomborg, 2020). It is also well-known that climate impacts will harm poorer countries more than richer countries, partly because poorer countries are more exposed, partly because they tend to be in already hotter places, and partly because being poor means less adaptive capacity (Tol, 2019).

These considerations have to be compared to the poorest nations on the planet growth: GDP of Sub-Saharan Africa countries, among the poorest in the world, has grown by about 7 times in the last 50 years while the Latin America countries growth was around 5 times (OWDGDP, 1970) with a consequent significant decrease of the population share living in extreme poverty (OWDpoverty, 1970).

It should therefore be concluded that, although in the last 50 years climate change may have had a negative impact on the economic growth of the poorest countries in the world, in the same period these countries have had a GDP increase at least one order of magnitude higher than this possible impact and this is in line with the IPCC conclusion: *'evidence for impacts of long-term climate change is still limited'* (IPCC-AR6-WG2, 2022, p. 2414).

In this context it is interesting to analyse two socio-economic indicators recently defined by the World Bank: the Global Prosperity Gap and the Population below poverty line. The Global Prosperity Gap captures how far a society is from \$25 per person per day (using 2017 purchasing power parity \$\$), which is close to the income of a typical person living in a country that enters high-income status. The Prosperity Gap is defined as the average factor by which incomes must be multiplied to reach the \$25 standard for every member of that society. The Prosperity Gap decreases (or welfare improves) with rising incomes and decreases even faster when incomes of the poor grow more rapidly; in other words, the decrease is greater through inclusive economic growth (WB-GPG, 2025). Population below poverty line is the percentage of the population living on less than \$2.15 a day at 2017 purchasing power adjusted prices (WB-PBP, 2025). Both indicators have improving trends as summarised in Table 1.

4.6. Displacement and migration

There is historical evidence of climate-related migrations, such as those caused by the American Dust Bowl, which led to significant internal migrations in the USA (Dust, 1929).

Increasing research focuses on the relationship between climate change and migration, though gaps remain in understanding this complex issue. Migration varies widely, from internal to international movements and from seasonal displacement to permanent resettlement. It can be triggered by slow-onset events like warming, droughts, and land degradation or fast-onset events like floods and hurricanes, with differing outcomes depending on the type of event (Cattaneo et al., 2019).

Migration is one of several adaptation strategies to climate change. Alternatives include agricultural adaptations, urban settlement adjustments, informal credit reliance, and social protection policies, which may complement or substitute migration. Climate change can influence income disparities between origin and destination countries, heighten economic uncertainty, or affect socio-political factors, all impacting migration likelihood (Cattaneo et al., 2019).

Despite growing research, the environmental – migration nexus remains poorly understood. The relationship between environmental factors and migration is neither deterministic nor uniform across regions and time. Findings show that environmental conditions are rarely the sole driver of migration; economic resources significantly moderate this relationship (Hoffmann et al., 2020). Literature indicates slow-onset events often result in voluntary migration or immobility, while fast-onset events lead to involuntary migration and short-term movements. Climate factors are generally one among many influencing migration decisions (Cattaneo et al., 2019).

There are also studies pointing to:

Misleading claims about mass migration induced by climate change continue to surface in both academia and policy. This requires a new research agenda on ‘climate mobilities’ that moves beyond simplistic assumptions and more accurately advances knowledge of the nexus between human mobility and climate change. (Boas, 2019)

A specific study on the XXI century second decade Syrian civil war concludes that there is no clear and reliable evidence that climate change was a factor in Syria’s pre-civil war drought; that this drought did not cause anywhere near the scale of migration that is often alleged; and that there exists no solid evidence that drought migration pressures in Syria contributed to civil war onset (Selby et al., 2017).

The AR6 part dedicated to migration concludes that the impact of long-term climate changes on human migration patterns has not been quantified due to data limitations. However, weather extremes are more influential on temporary and short-distance movements, such as urbanisation, rather than permanent or international migration (IPCC-AR6-WG2, 2022, p. 2428).

5. Towards a possible metrics

Our concept of a quantitative approach to climate drivers and their impacts is summarised in Table 1. Without claiming to be exhaustive, we have compiled a selection of CIDs and various RINDs with the aim of highlighting their status and temporal variability over a period ranging from 1951 for the longest series, up to 2024 for the most recent, requiring a minimum length of 20 years. Most of the indicators are global, with only a few cases, such as the CNR-IRPI flood series, where high-quality indicators available solely at a local level have been included. Among the 42 selected indicators, 23 are classified as physical-environmental, 10 as socio-economic, and 10 relate to human health. The indicators in Table 1 were

analysed using the Mann-Kendall test to assess the significance of any existing temporal trends. Indicator plots can be found in Supplementary Materials Appendix 3.

The selected indicators reflect the principle that a metrics useful for detecting a climate crisis should consider the consequences of realised risks related to climate change on natural and human systems, particularly where risks arise from the interactions of climate-related hazards (including extreme weather and climate events), exposure, and vulnerability. Impacts generally refer to effects on lives, livelihoods, health and wellbeing, ecosystems and species, economic, social and cultural assets, services (including ecosystem services), and infrastructure (United Nations Statistics Division, 2024).

Among the various CIDs presented in Table 12.12 (IPCC-AR6-WG1, 2021, p. 1856), cyclones and floods have been specifically analysed, as they are among the most impactful events, causing death, injury, loss of livelihoods, displacement, and placing a significant burden on societies, economies, and the environment (EMDATdcs, 2025). Other CIDs reported in Table 1 include global mean surface temperature and global mean precipitation, selected because they are fundamental drivers of ecological and socio-economic systems.

Atmospheric CO₂ at the surface is one of the main drivers of the climate system and simultaneously a crucial element for photosynthesis, contributing to global plant biomass. This latter is expressed as the Leaf Area Index (LAI), a dimensionless quantity characterising plant canopies and defined as the one-sided green leaf area per unit ground surface area.

The Arctic region is the most critical area regarding the observed ice decline in recent decades, with ice volume data simulated by the PIOMAS model (PIOMAS, 1979).

Global Gross Domestic Product (GDP) has been included among the indicators as a general index to monitor global wealth and productivity.

Results reported in Table 1 show that most indicators do not exhibit worsening trends. This is significant for defining effective and sustainable adaptation policies aimed at enhancing the resilience of socio-economic and environmental systems.

6. Discussion

An analytical approach to the 'climate crisis' concept based on CIDs and RINDs has been proposed enhancing the IPCC CID-based framework (CID, 2022). This approach is still provisional and reliant on some statistical scientific indicators. The initiative aims to move beyond the qualitative use of the term 'climate crisis' by establishing a broad, shared, and quantitative methodology. The final goal is to provide a robust, data-driven assessment through updated time series and standardised statistical analysis, supported by interdisciplinary collaboration.

To this end, we emphasise the importance of:

- periodic (at least annual) series updates by operational organisations such as FAO, WHO or other international entities that collect and manage time series useful for this purpose;
- an alarm criterion based on predefined statistical methodologies (e.g. exceeding specific thresholds, significant trend variations, etc.);
- multiscale analysis (global, national, regional). All systems on our planet – from the climate system to ecological and socio-economic systems – can be effectively

approached from the global scale down to the microscale. While our work has been developed at a global scale with some exceptions, the analysis can be extended to smaller scales (United Nations Statistics Division, 2024).

We must emphasise that impact indicator time series often bear the signature of adaptation, and that other human factors tend to outweigh climate factors. For instance, the influence of climate on conflicts is considered minor compared to dominant conflict drivers (IPCC-AR6-WG2, 2022, p. 2428; Mach, 2019). Similarly, the human footprint on vector-borne diseases may be more significant than climate change, as evidenced in the twentieth century by the decline in malaria endemicity and mortality despite rising global temperatures (Carballar-Lejarazú et al., 2023; Climate Adapt, 2022; Rossati et al., 2016). The reduction in deaths caused by extreme weather events can partly be attributed to improvements in civil protection systems. These examples demonstrate that adaptation often proves more effective than mitigation. Another example of anthropogenic influence unrelated to climate concerns wildfires: many studies report increases in burned areas linked to a warming climate over recent decades across much of North America. However, the rate of burning sites in the USA in recent decades has been much lower than historical rates across most of the continent, a disparity attributed to aggressive fire suppression and disruption of traditional burning practices (Parks et al., 2025). Furthermore, global deforestation trends fit within complex land use patterns where climate plays a secondary role; more specifically, remote sensing data reveal an increase in forest areas at mid-to-high latitudes in the northern hemisphere, while deforestation driven by the expansion of intensive agriculture is observed in subtropical regions (FAO, 2022; Pendrill et al., 2022; Song et al., 2021; Winkler et al., 2021).

Most of the time series in Table 1 do not show signs of deterioration. This is important to highlight, as it suggests we still have sufficient time to develop effective and sustainable adaptation policies aimed at enhancing the resilience of socio-economic and environmental systems. For example, in the case of droughts, the use of dry farming techniques, which optimise the exploitation of water resources during periods of scarcity, and the creation of water reservoirs, which can also contribute to renewable energy production and flood mitigation and prevention, can be envisaged. Regarding forest fires, key adaptation measures include the rational management of forest litter, the establishment of firebreaks to prevent the spread of fire, and the maintenance of adequate firefighting services.

Since the observed emergence of most of the CIDs presented in IPCC Table 12.12, and confirmed by the analysed updated time series, as well as most of the RINDs in Table 1, do not exhibit worsening trends, our overall view is that the 'climate crisis', as portrayed by many media sources today, is not evident yet. Nevertheless, it remains extremely important to improve and standardise monitoring activities and to develop adaptation strategies based on high-quality data.

Note

1. (Disability-adjusted life year). The number of years lost owing to morbidity or mortality of a disease. This measure is preferable to simple mortality measures, as it better captures the disease burden for debilitating but often self-limiting diseases like dengue and malaria.

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Disclosure statement

No potential conflict of interest was reported by the author(s).

Data availability statement

The data that support the findings of this study are publicly available following the links specified in the article; data are available from the corresponding author upon reasonable request.

ORCID

Gianluca Alimonti  <http://orcid.org/0000-0002-7128-9046>

Luigi Mariani  <http://orcid.org/0000-0002-1144-506X>

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