Climate Change and Health

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Introduction

Human health, morbidity, mortality and longevity are significantly impacted by climate. This review examines the evidence for past, present and possible future health impacts of climate change on disease and disease vectors, on extreme weather events, floods, droughts, heatwaves and wildfires, on food and famine, and on social and mental health. It will also examine health issues in relation to various energy sources and conclude with an overview of priorities.

Warmth, Wealth and Health

For over two million years, Earth has been in the grip of an Ice Age interspersed every 100,000 years or so with interglacial warm periods lasting about 10,000 years. While the present warming began about 18,000 years ago, the Holocene interglacial dates from 11,700 years ago when South Greenland warmed 7°C in just 50 years.[1] The human population exploded in a warmer world. Agriculture began and civilisations arose during the Holocene Climatic Optimum,[2] globally warmer than now[3] for several millennia in Russia[4] and up to 7°C warmer than now in the Arctic.[5] Subsequent gradual cooling has been interrupted by the Minoan, Roman and Medieval warm periods, during which mankind multiplied and flourished.

When rapid cooling after the Roman Warm Period ushered in the Dark Ages, the bubonic Plague of Justinian (541-542CE) killed 13% of the world's population, 25 million people, and twice that over the next two cold centuries.[6] Civilisation again flourished during the Medieval Warm Period,[7] after which a cold and miserable Little Ice Age (LIA) resulted in frequent widespread crop failures, mass starvation, disease and depopulation.[8] Crop failures over successive summers from 1315 produced the Great Famine of Europe[9] with "extreme levels of crime, disease, mass death and even cannibalism."[10] The Black Death (1346-1353) wiped out 30-60% of Europe's population and up to 200 million people across Eurasia.[11]

Global rewarming since the 18th century, plus better housing, sanitation, food and water supplies has greatly benefited human health and prosperity. Deaths from typhoid and tuberculosis declined dramatically during pre-antibiotic 20th century warming (1910-1945).[12] As temperatures rose, mortality from all causes fell.[13] From a billion people in 1800, the global population had doubled by 1927, and again to four billion in 1974. It reached six billion in 2000 and is now 7.6 billion people.[14]

Northern winters have nevertheless remained more lethal than summers.[15] In the United States, winters were 13% more lethal in 1952-1967 and even more so (16%) despite global warming in 1985-1990, largely due to the increased availability and affordability of air-conditioning.[16] Despite warming from 1964 to 1998, Davis *et al.* (2003)[17] found a 74.4% decline in heat-related mortality in 28 of the largest U.S. cities. They estimated that another 1°C increase would further reduce the net mortality rate.[18] Analysing over 74 million deaths in 384 locations across 13 countries, Gasparrini *et al.* (2015)[19] found that cold weather was twenty times more lethal than hot weather. About 7.7% (3% to 11%) of all deaths were related to non-optimal temperatures, nearly 7.3% to cold and only 0.42% to heat. The 2017-18 UK winter death-toll was the worst in 42 years,[20] due largely to fuel poverty[21] affecting almost a third of the elderly.[22]

Life expectancy is strongly associated with wealth or GDP per capita (Fig. 1).[23] Both have been increasing in all regions of a warming world since the industrial revolution (1770-2015).[24]

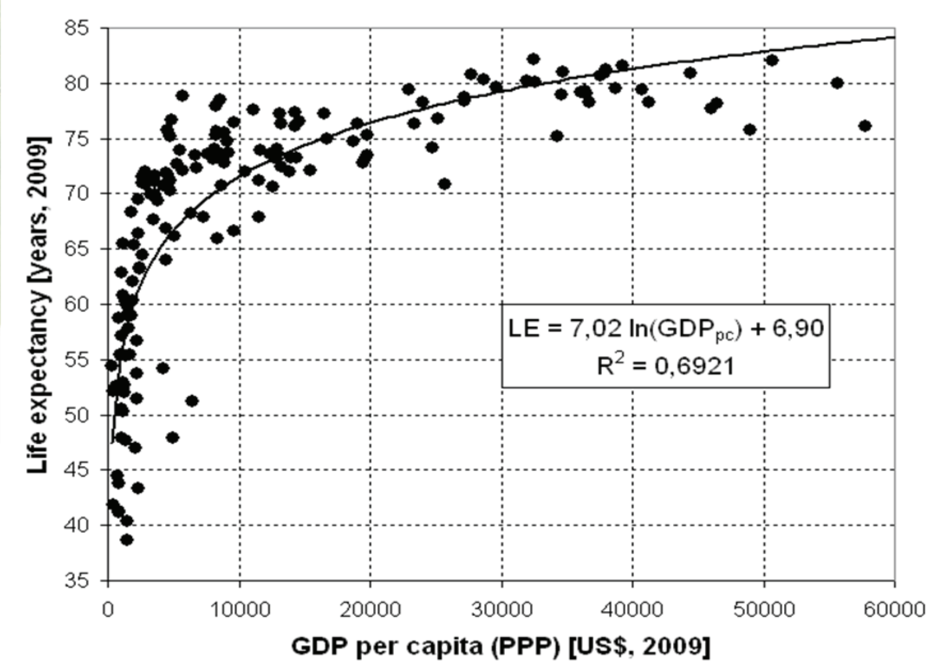


Figure 1: The Preston curve of Life Expectancy at birth increasing with GDP per capita
Source: *https://en.wikipedia.org/wiki/Preston_curve*

Fossil fuels have cheaply and reliably powered industry, mechanised agriculture and transport, helped to end slavery and emancipate women and children, propelled urbanisation with its sewerage and safe water supplies, provided electricity for heating, refrigeration and air-conditioning, and facilitated better hospitals and health care. Fossil fuel products and by-products (fertilisers, pesticides and carbon dioxide) also boosted food production and human nutrition. Fossil fuels also contributed to global warming; by how much no one can say precisely, but probably about half earlier estimates.[25] While it is possible to have too much of a good thing, we are a long way from doing that globally. Richard Tol (2010)[26] analysed fourteen peer-reviewed papers examining the likely impacts on GDP and human welfare of warming this century – by 1°C (2 studies), 2.5°C (10 studies) and 3°C (2 studies) – and found that that another 1-2°C would probably increase global GDP (Fig. 2). As shown in our White Paper, ***A Primer on Carbon Dioxide and Climate,***[27] global warming this century is unlikely to exceed 1°C, even without climate action. Dire predictions are based on flawed models, unhealthy exaggerations and a failure to factor in human ingenuity.[28]

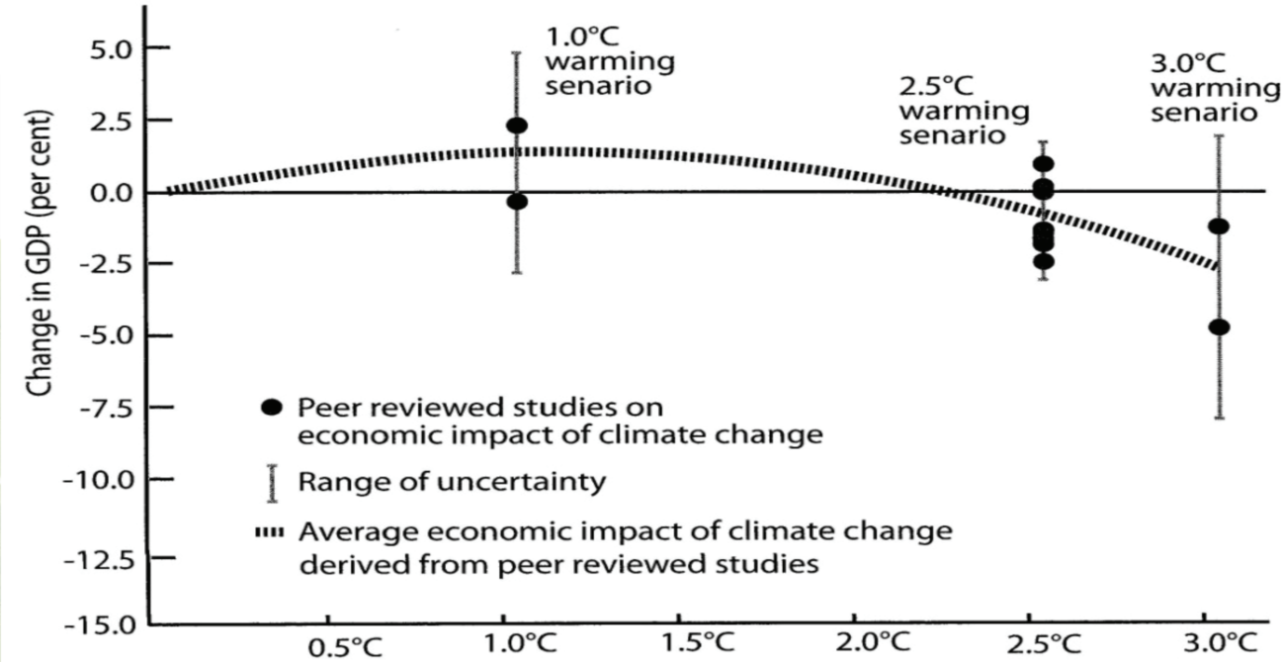


Figure 2: Projected economic impact of global warming of 1^{o}C, 2.5^{o}C and 3^{o}C over the 21st century.

Source: Tol, 2010, derived from UN data

Temperature and Disease

By absorbing some solar radiation by day and emitting it to the surface by night, greenhouse gases moderate the **diurnal temperature range (DTR)**.[29] Whereas solar warming increases daytime maximum temperatures, greenhouse gases primarily impact nocturnal minimums. Knappenberger *et al.* (2001)[30] nicely demonstrated this in a study of night-time temperatures across the U.S. during 1910-1939 and 1970-1997. Whereas the first warming period, due primarily to solar **influences**, showed a fairly even distribution across the year, the latter warming period impacted primarily the coldest nights (Fig. 3). Cold nights have been decreasing and warm nights increasing right across the globe.[31] Temperature variability has thus reduced.[32]

High temperature variability is associated with increased cardiovascular and respiratory mortality in the United States.[33] For every 1^{o}C increase in DTR, cardiac mortality increases by 1.7% in Hong Kong[34] and by up to 3.2% in Shanghai.[35] Emergency visits to the Huashan Hospital (Shanghai) with respiratory infections were 1% and 2% higher for every 1^{o}C increase in the current-day and 2-day moving average DTR respectively.[36] Increasing atmospheric CO_2 actually ***reduces*** **DTR**.

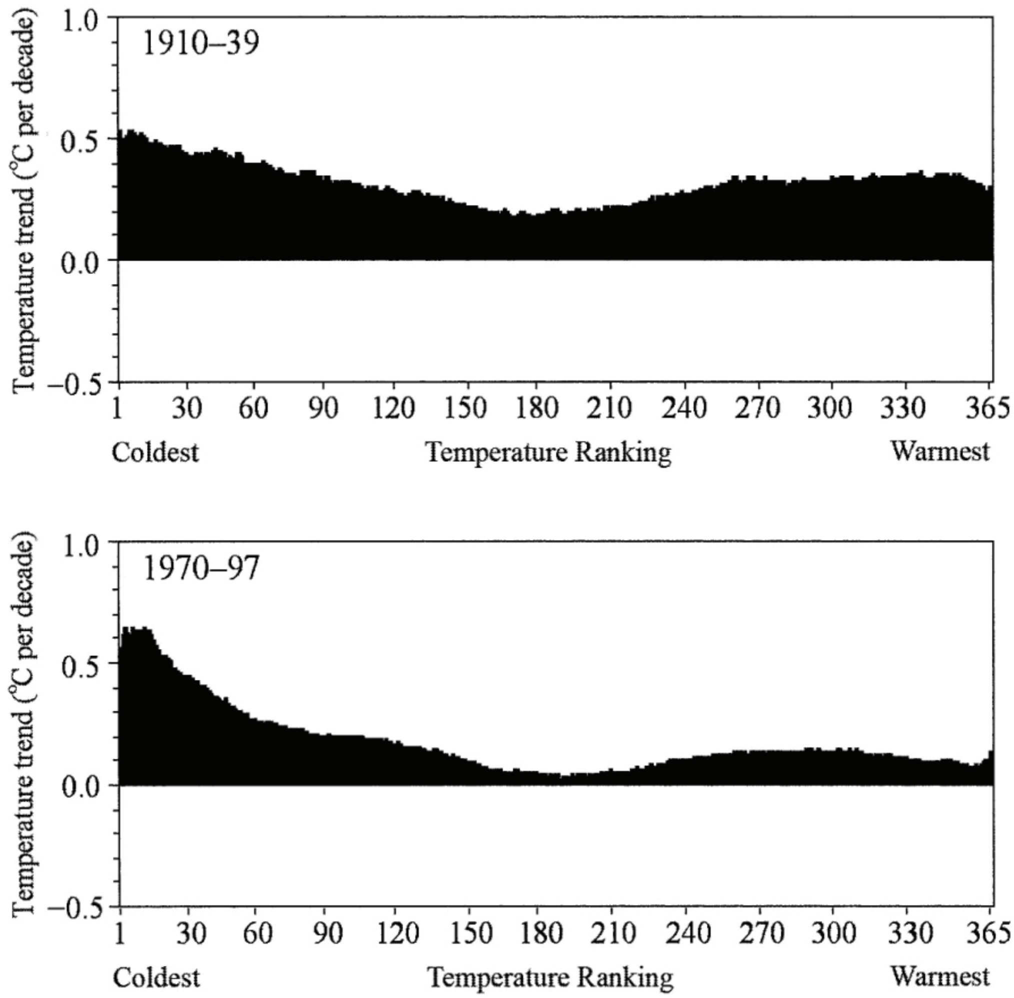


Figure 3: Nocturnal temperature trends for 1910-39 (Top) and 1970-97 (Bottom): trends plotted for the coldest nights from the left (No. 1) to the warmest (No. 365).
Source: Knappenberger, Michaels and Davis, 2001

Asthma, now affecting over 300 million children,[37] has been increasing by 50% per decade in many countries.[38] The Centers for Disease Control (CDC) linked[39] this to climate change, but alternative explanations include increasing hygiene,[40] antibiotic use[41] and the pasteurisation[42] of cow's milk.[43] Rising CO_2 concentrations and temperatures may increase ragweed pollen numbers and perhaps other pollens associated with respiratory allergies,[44] but ragweed pollen allergenicity can vary four-fold,[45] and pollen numbers are spatially and temporally highly variable.[46] Ragweed pollen has actually been decreasing in

Zurich since 1982, and the major allergenic pollens have been declining in Basel, Switzerland since the early 1990s, as has the incidence of hay fever.[47] The Poaceae family of herbaceous grasses affects 80% of pollen allergy sufferers in Europe.[48] Jato *et al.* (2009)[49] found that the Poaceae pollen count had declined in four Spanish cities since 1993, by about 75% in Lugo and 80% in Santiago. They also found a delayed onset and shorter duration of the atmospheric pollen season. Xu *et al.* (2013)[50] found that childhood asthma increased 0-9 days after a DTR above 10°C, and also a 31% increase in emergency department admissions per 5°C increment in DTR. By reducing the DTR, CO_2 may actually be reducing the incidence of asthma.

Eczema and associated itch is more common in winter due to drying of the skin. A study of atopic eczema in the mountainous area of Davos, Switzerland in 1983–1989 found itch-intensity to be inversely correlated with temperature.[51] Thirty Norwegian children improved in severity of eczema, quality of life, skin bacterial culture and medication usage after spending a month in the Canary Islands, and the improvement compared to a matched control group was still apparent three months later.[52]

Gastroenteritis, which caused about 1.3 million deaths globally in 2015,[53] is predicted to increase with global warming.[54] Xu *et al.* (2013)[55] found that even in Brisbane, Queensland, “a 1°C increase in diurnal temperature range was associated with a 3% increase of Emergency Department Admissions for childhood diarrhea.” By reducing DTR, CO_2 may actually be reducing the global incidence of severe gastroenteritis.

Cholera is now confined to developing countries in the tropics and subtropics (Fig. 4) where it afflicts 3-5 million people and kills about 100,000 annually.[56] After spreading from Europe to London in 1831, an epidemic wiped out 50,000 people in just over a year. When another epidemic broke out in 1848, Dr John Snow[57] performed the world’s first epidemiological studies, linking it to contaminated water. Nearly a century and a half later, a paper in the prestigious journal *Science*[58] linked a 1991 outbreak in South America to climate change. The real cause, however, was a failure of the Peruvian authorities to properly chlorinate water supplies.[59] Climate change can be a handy scapegoat for government failure!

Respiratory disease is strongly related to temperature. Coughs, colds and influenza are far more prevalent in winter. Consultations for respiratory disease in London (1992-1995) increased linearly by 10.5% per degree (below 5°C).[60] Keatinge and Donaldson (2001)[61] found a linear increase in mortality from respiratory disease in Londoners aged over 50 as the temperature fell below 15°C. The bronchiolitis season in central England was shortened by about three weeks for every 1°C of annual warming from 1981 to 2004.[62] Carder *et al.* (2005)[63] analysed non-violent deaths in Scotland (1981-2001) and found that every 1°C drop in the daytime mean temperature below 11°C on any one day was associated with a 4.8% increased respiratory mortality over the following month. Respiratory-related deaths were

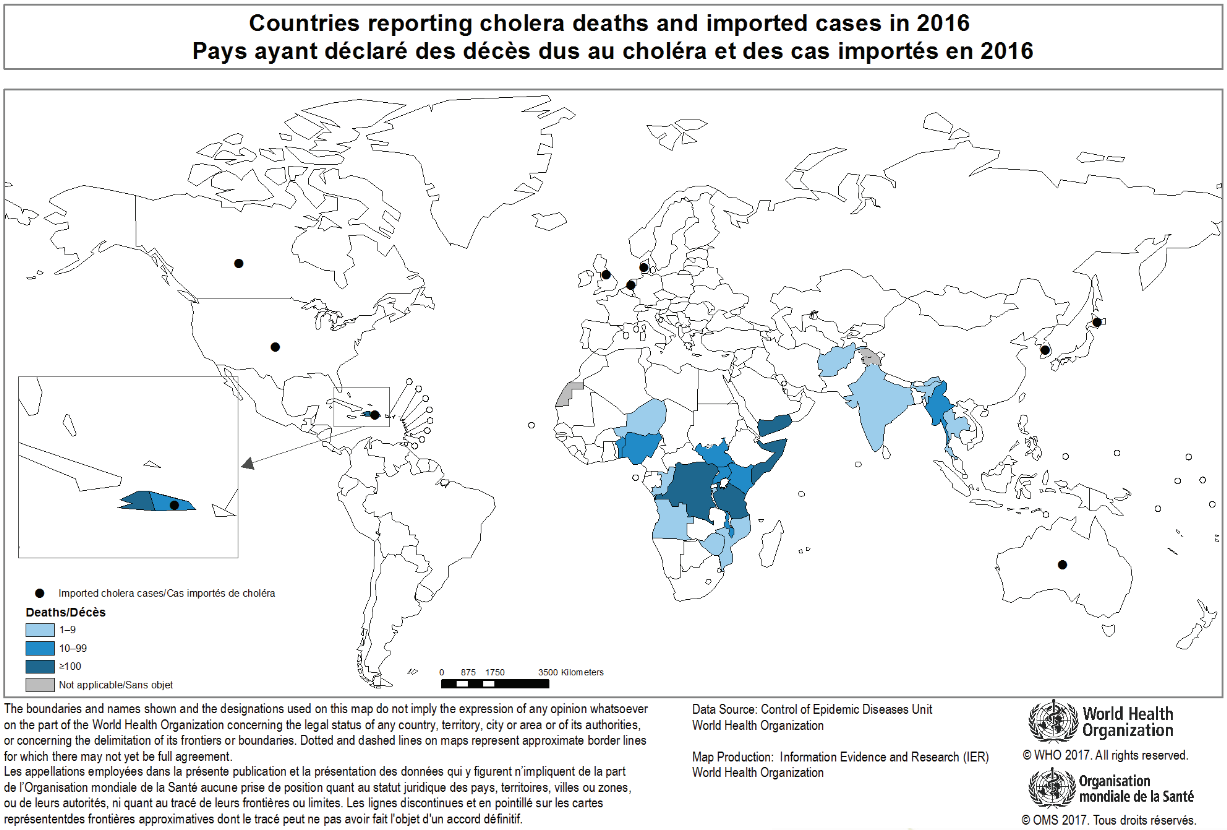


Figure 4: Distribution of cholera in 2016 as reported to the World Health Organisation.
Source: http://gamapserver.who.int/mapLibrary/Files/Maps/Global_Cholera(WER)_2016.png

47% higher in winter than in summer in Oslo during the period 1990-1995.[64] Even in Sao Paulo, Brazil, Gouveia *et al.* (2003)[65] found the fewest respiratory deaths in all age groups occurred at 20°C; mortality increased twice as much per degree below 20°C as it did above 20°C. DTR is a risk factor for chronic obstructive pulmonary disease (COPD) mortality.[66]

Cardiovascular disease (CVD) is the major cause of death worldwide. It presents more often in winter and is more often fatal on cold days.[67] A study in the Hunter Region of New South Wales, Australia (1985-1990) found that "fatal coronary events and non-fatal definite myocardial infarction were 20–40% more common in winter and spring than at other times of year"; coronary deaths were up to 40% more likely to occur on cold days than at moderate temperatures.[68] Cardiovascular mortality was 15% higher in the colder months October-March than in April-September in Norway (1990-1995),[69] 33% higher in Californian winters (1985-1996)[70] and 50% higher in mid-winter than in mid-summer in both London (1994-1996)[71] and Israel (1976-1985),[72] despite summer temperatures often exceeding 30°C.

Braga *et al.* (2002)[73] compared cardiovascular mortality in "hot" cities in the southern United States with "cold" cities in northern states. They found neither hot nor cold weather had much impact in the "hot" cities but significantly increased the mortality in the "cold" cities, where the cold-day effect was five times as great as the hot-day effect and persisted for days. There was a deficit of deaths for a few days after the hot days, indicating that hot days had a "harvesting effect" on those who were about to die. Cagle and Hubbard (2005)[74] examined the relationship between temperature and out-of-hospital cardiac deaths in people over 54 years of age in King County, Washington (USA) over the period 1980-2000; mortality rose by 15% on days with maximum temperatures below 5ºC and dropped by 3% on days with maximum temperatures over 30ºC. In Japan (1970-1999), heart disease and stroke mortality rates were nearly twice as high in winter as in summer. [75]

Stroke is more common in cold weather. Novosibirsk, Siberia has one of the world's highest rates of stroke, 87% being ischaemic (due to blocked cerebral blood vessels) and 32% higher on days with low ambient temperature.[76] A similar association was found in Korea, where Hong *et al.* (2003)[77] found a 24-48-hour lag between exposure to cold and the onset of stroke. A study of World Health Organisation (WHO) data on women aged 15-49 from 17 countries in Africa, Asia, Europe, Latin America, and the Caribbean found that a 5ºC reduction in mean air temperature was associated with a 7% increase in hospitalisation with stroke.[78] Aneurismal subarachnoid haemorrhage is also strongly correlated with winter and cold weather.[79]

Future Mortality: Keatinge and Donaldson (2004)[80] report: "even in climates as warm as southern Europe or North Carolina [USA], cold weather causes more deaths than hot weather. . . global warming will reduce this at first [but] the improvement is not likely to continue without action to promote defences against cold." They conclude: "the overall effect of global warming on health can be expected to be a beneficial one." Evaluating the future impact of unchecked global warming on human health, Bosello, Roson and Tol (2006)[81] projected 1.4 million fewer deaths annually to 2050 and a lower mortality rate until at least 2200.

The Lancet, however, published a paper by Gasparrini *et al.* (2017)[82] indicating that without mitigation, heat-related mortality will overtake cold-related mortality in Southeast Asia very soon, in Central and South America by mid-century, and in Southern Europe and overall before 2100. Using the worst emissions scenario (RCP8.5), they projected temperature increases ranging from 3.3ºC for Australia to 4.9ºC for North America, and 4.1ºC globally, above the 2010-19 mean. The RCP4.5 scenario, projecting a mean global increase of 1.7ºC, resulted in cold remaining more lethal than heat except in SE Asia and South America (Fig. 5). Russia, Alaska, Africa, the Middle East, northern and central Asia, India and Indonesia were ignored in this study, as was **adaptation and demographic changes**. The authors thus caution: "The reported figures should therefore be interpreted as potential impacts under well defined but hypothetical scenarios, and not as predictions of future excess mortality."

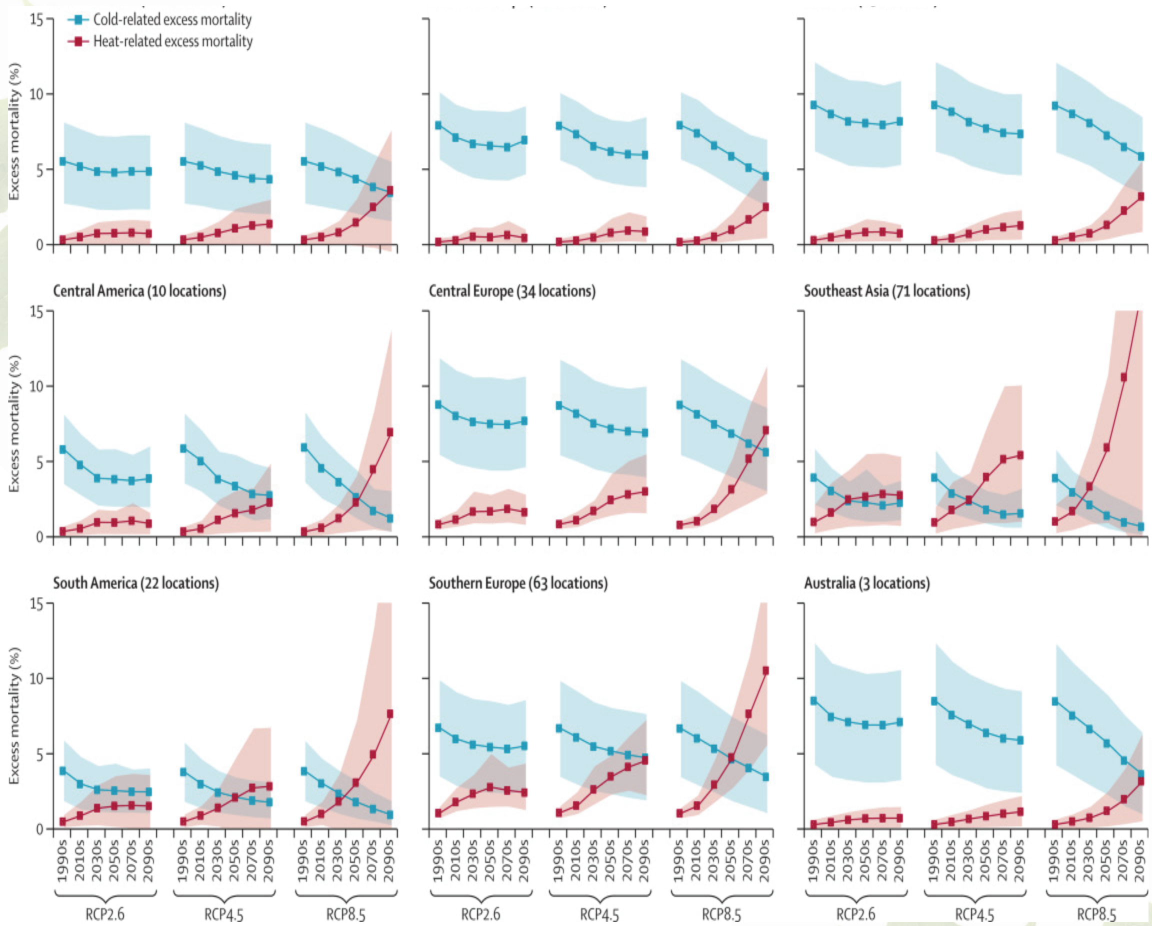


Figure 5: Projected changes in cold-related and heat-related excess mortality over the 21st century for nine regions and three emissions scenarios: RCP2.6, RCP4.5 and RCP8.5

People are not potted plants – they take steps to reduce risk. Oren Cass[83] cautions: "If a projection of climate-change cost ignores **adaptation**, we can safely ignore it." When Christidis *et al.* (2010) [84] factored adaptation into an analysis of the benefit of global warming on the mortality rate in England and Wales during the period 1976-2005, they found the lives-saved to lives-lost ratio increased from 29.4 to a phenomenal 121.4.

Recent **demographic changes** favour warmth: from 2006 to 2016, Australia's hottest capital city, Darwin (latitude 12°S) had the nation's fastest population growth (29%).[85] Southerners flock to sunny Queensland every winter, and many stay. So many U.S. citizens move from the cold northeast states to warm southwest states that it contributed 3-7% of the late 20th century gains in longevity, and is thought to delay about 4,600 deaths annually.[86] People are still voting with their feet on climate change. It is religious, political and tribal conflict that has been driving migration in Africa, the Middle East and Myanmar. We see no signs of Singaporeans, Malaysians or Indonesians fleeing the heat.

Disease Vectors

Vector-borne diseases[87] account for over 17% of all infectious diseases, causing more than 700,000 deaths annually. Vector-borne infection is regarded by the IPCC as a major climate change challenge to human health.[88] It is postulated that global warming will indirectly impact human health by spreading the following disease vectors to areas that have been too cool for them.[89]

Vector	**Species**	**Diseases**
Mosquitoes	*Anopheles*	Malaria – P. falc*iparum, P. vivax, P. ovale and P. malariae*
	Aedes	*Chikangunya, Dengue, Yellow Fever, Ziga*
	Culex	West Nile Virus
Ticks	*Ixodes*	Tick-borne encephalitis, Lyme disease
Sandflies		Leishmaniasis

Malaria is caused by protozoan parasites belonging to the Plasmodium type, transmitted by the female Anopheles mosquito. It was endemic for millennia in Europe and England;[90] in areas near England's marshes, 17th century burial records reveal a mortality rate comparable to that in sub-Saharan Africa today.[91] Apart from epidemics during the unusually hot summers of 1848 and 1859, there was a near-linear decline in endemic malaria in the UK as the climate warmed from 1840 to 1910. It disappeared in 1953, and re-establishment with further warming is considered highly unlikely.[92] Endemic malaria in Finland likewise faded out over two centuries of warming with limited or no counter measures or medication, leading Hulden and Hulden (2009) [93] to conclude that, "malaria in Finland basically was a sociological disease and that malaria trends were strongly linked to changes in the human household size and housing standard." Helsinki had its last malaria epidemic in 1902, but parts of northern Europe including the Arctic Circle had devastating epidemics until the middle of the 20th century.[94]

A malaria epidemic affected 30% of the population of the Tennessee River Valley in 1933.[95] During a period of rapid warming from 1916 to 1937, there was a four-fold decline in deaths from malaria in Mississippi, the only significant correlation being with family income: the higher the income the fewer the deaths.[96] Malaria remained endemic in 36 states until the CDC was created to tackle it after World War II. Swamps were drained, agricultural practices were changed, cases were isolated from mosquitoes and treated, mosquito nets and DDT were widely used and millions of homes were sprayed. The U.S. was considered malaria-free in 1951.[97] During another period of rapid warming (1977-2001), the incidence of malaria in northern Thailand declined by 6.45% per year, from 41.5 to just 6.72 cases per 100,000 people.[98] The global mortality rate per capita has declined by 95.4% since 1900.[99] The 20th century also saw a dramatic decline in malarial endemnicity globally (Fig. 6).

Africa now bears the highest infection burden of any continent, with nearly 200 million cases reported in 2006. Malaria kills 0.7 to 2.7 million people every year, 90% of them in Africa, and three out four are children. Studies extending over 10-32 years found no correlation between temperature or rainfall and malaria incidence in western Africa,[100] or at four highland sites in east Africa[101] or in western Kenya.[102] A comprehensive study across Africa over an 85-year period (1911-1995) found a correlation with precipitation in Southern Mozambique but none anywhere with temperature.[103] In a review paper, Rogers and Randolph (2006)[104] attribute the observed increase in malaria in many parts of Africa it to "land-cover and land-use changes and, most importantly, drug resistance rather than any effect of climate," noting "the recrudescence of malaria in the tea estates near Kericho, Kenya, in East Africa, where temperature has not changed significantly, shows all the signs of a disease that has escaped drug control following the evolution of chloroquine resistance by the malarial parasite."

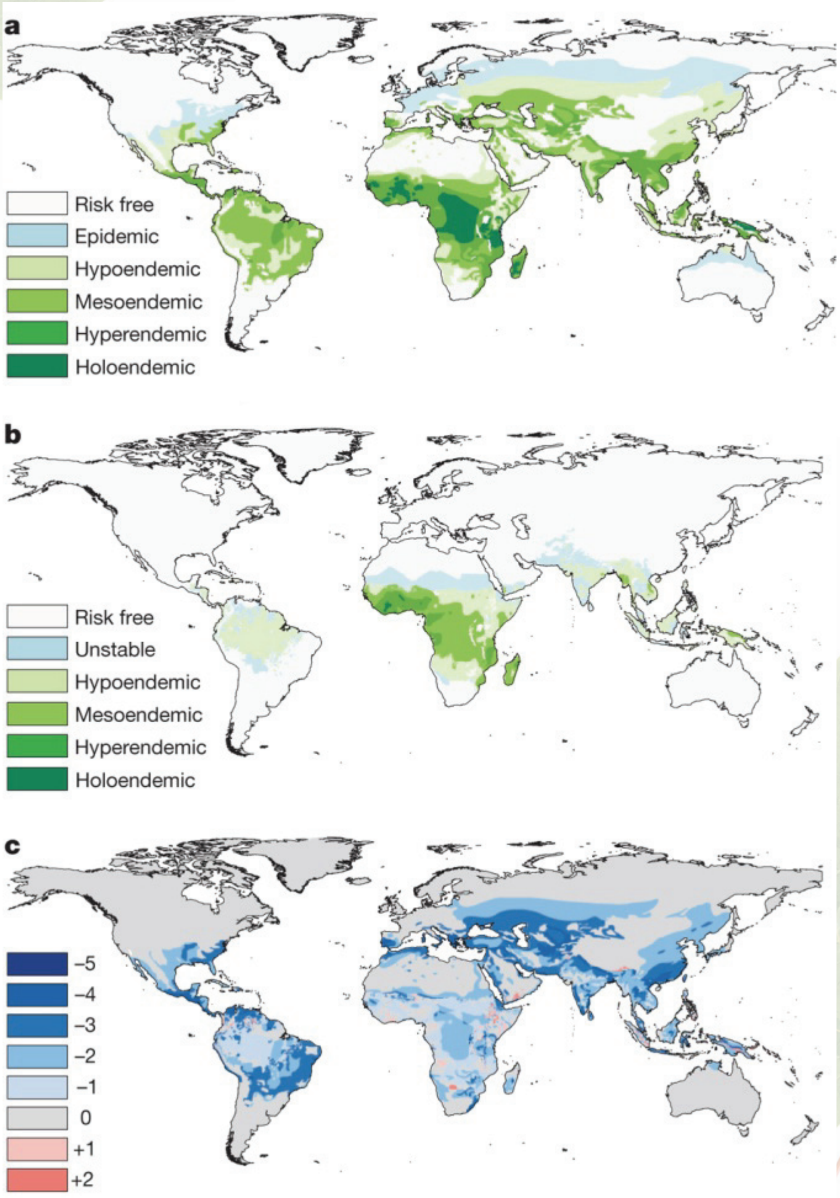


Figure 6: Changing global malaria endemicity 1900-2007. Source: Gething *et al.* 2010[105]

- **a,** Pre-intervention endemicity (approximately 1900)
- **b,** Contemporary endemicity for 2007 based on a recent global project to define the limits and intensity of current *P.falciparum transmission*.
- **c,** Change in endemicity class between 1900 and 2007. Negative values denote a reduction in endemicity.

Haque *et al*. (2010)[106] analysed monthly malaria case data for the malaria endemic district of Chittagong Hill Tracts in Bangladesh from January 1989 to December 2008. They found no correlation with temperature, rainfall or humidity, but a strong negative association with the normalized difference vegetation index (NDVI), a satellite-derived measure of surface vegetation greenness. They state: "each 0.1 increase in monthly NDVI was associated with a 30.4% decrease in malaria cases" probably due to increasing insectivorous bird populations. By greening the Earth,[107] CO_2 may actually be reducing malaria risk.

It is thought that global warming will allow malaria to climb to higher altitudes.[108] Before the introduction of DDT and other public health measures, however, malaria transmission occurred much higher than now, at up to 2,600m in Kenya, 2,450m in Ethiopia, 2,500m in the Himalayas, 2,180m in Argentina and 2,773m (near thermal springs) in Bolivia.[109] After considering forest clearance, agriculture, urbanisation, health infrastructure, drug and insecticide resistance, civil strife and other influences on endemic malaria in the Highlands of Kenya and New Guinea, Paul Reiter of the Insects and Infectious Disease Unit of the Institut Pasteur in Paris, France concluded: "simplistic reasoning on the future prevalence of malaria is ill-founded; malaria is not limited by climate in most temperate regions, nor in the tropics, and in nearly all cases, 'new' malaria at high altitudes is well below the maximum altitudinal limits for transmission." He also states "obsessive emphasis on 'global warming' as a dominant parameter is indefensible; the principal determinants are linked to ecological and societal change, politics and economics."

When GDP per capita was included in models of future global malaria distribution, climate change proved to be much weaker.[110] Simplistic models project an increase with climate change, but one using five variables and a high-emission scenario actually produced a 0.92% **decrease**. Economist, Indur Goklany (2004)[111] calculated that the malaria death toll could be halved through a combination of proven measures for a tiny fraction of the cost of mitigation.

Chikungunya virus (CHIKV) was first isolated on the Makonde Plateau of Tanzania during an outbreak in 1953.[112] The name is Makonde for "contorted or bent up" with incapacitating arthralgia. The primary host in Africa are non-human primates and small mammals, and its primary vector is the mosquito *Aedes aegypti*. CHIKV has been spreading rapidly in recent decades but not due to climate change. *A. aegypti* escaped Africa centuries ago with the slave trade and established itself widely across tropical and subtropical regions (Fig. 7), even in southern Europe until the mid-1900s when it disappeared during a period of warming.[113] It recently re-established itself at Madeira, Portugal[114] and in the Caucasian region bordering the Black Sea.[115]

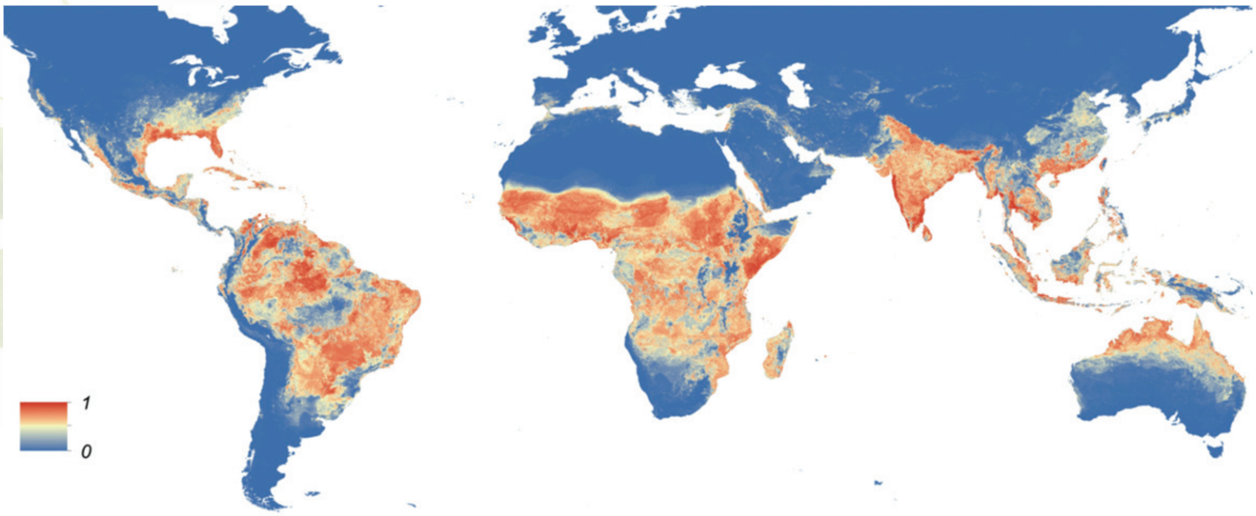


Figure 7: Global distribution[116] of *Aedes aegypti* in 2015. Source: Moritz UG Kraemer *et al*[117]

CHIKV broke out on Reunion Island and neighbouring Indian Ocean islands in 2005 and in India in 2006. It then spread to South-East Asia,[118] simultaneously undergoing a genomic micro-evolution which enabled it to be transmitted by *Aedes albopictus*, the tiger mosquito of SE Asia.[119] *A. albopictus*, which is intolerant to extreme heat,[120] has been adapting to cold climates in temperate regions such as Japan. It can hibernate over winter and produce eggs that are more cold-tolerant.[121] Adult mosquitoes can even survive freezing winters in suitable microhabitats.[122] It spread to Albania in 1979[123] and to Genoa, Italy in imported used tyres in 1990.[124] By 2007, it had spread extensively across southern Europe (Fig. 8). Ravenna in northern Italy experienced Europe's first CHIKV epidemic after the virus was introduced from India.[125] *A. albopictus* has recently spread westward in the continental United States, where locally acquired cases occurred in 2014,[126] but only travel-associated cases have been reported since 2015.[127]

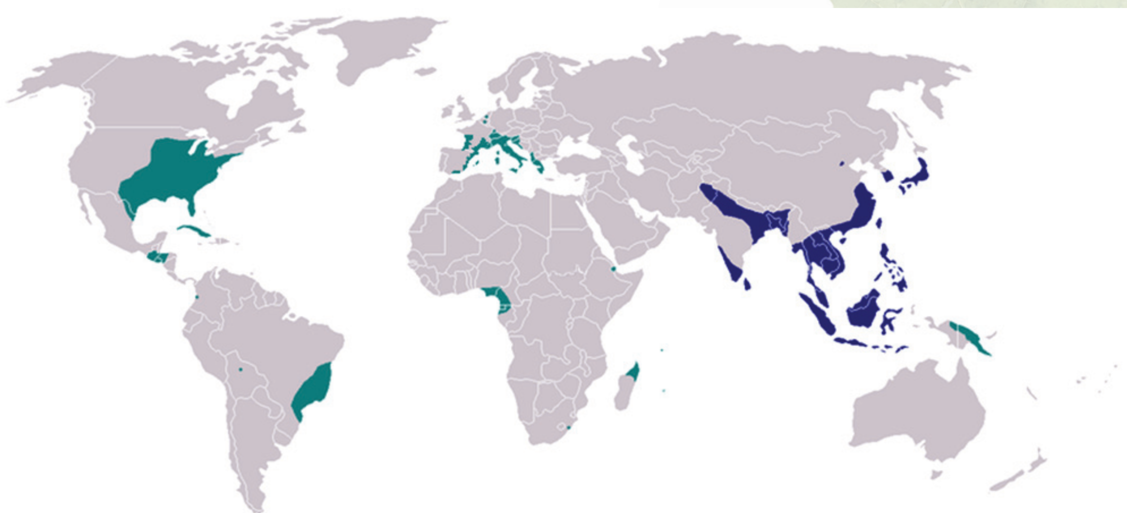


Figure 8: Distribution of *Aedes albopictus* as of December 2007 CDC[128]

Modelling by Fischer *et al.* (2013)[129] projected an increased risk "for Western Europe (e.g. France and Benelux-States) in the first half of the 21st century and from mid-century onwards for central parts of Europe (e.g. Germany). Interestingly, the southernmost parts of Europe do not generally provide suitable conditions in these projections." In other words, their emissions scenarios will make it too warm for A. albopictus to remain established in southern Europe. The reality, of course, is that no one knows what might happen this century; warming may be less than thought, vaccines and public health measures may control or even eradicate the virus from the developed world, it may mutate again, or more CO_2 may even reduce the incidence. Tuchman *et al.* (2003)[130] grew the quaking aspen (*Populus tremuloides*) (Michaux) trees at atmospheric CO_2 concentrations of either 360ppm or 720ppm for an entire growing season and fed the incubated leaf litter to four species of mosquito larvae to assess the effect on development. They found the larvae of *Aedes albopictus* had a mortality rate 2.2 times higher when fed the high-CO2 litter, which delayed the development of all larvae by 9-20 days. When there are so many variables, who can predict the future!

Dengue fever is arguably the most important vector-borne viral disease globally, infecting over 200 million people, 1% of them severely with over 20 thousand deaths annually.[131, 132, 133] A review of 16 studies, carefully selected from 75 papers with methodologies of varying quality, found dengue transmission to be highly sensitive to climatic conditions, especially temperature, rainfall and relative humidity.[134] Dire predictions[135] are usually based on the following facts: there has been a 30-fold increase over the past 5-6 decades; dengue is now endemic in 119 countries; the transmission zone has expanded to include half the world's population; further warming will lengthen the lifespan of the mosquito and shorten the extrinsic incubation period of the dengue virus, resulting in more infected mosquitoes for a longer period of time. [136] This must be weighed against other historical facts, scientific evidence and opinion:

- Endemic dengue has actually diminished or disappeared from some countries. In the United States, dengue and yellow fever were major public health problems during the cold 17th century but disappeared during the warm 20th century.[137] The CDC states: "As recently as the 1940s, large dengue outbreaks were documented in the United States reaching places as far north as Boston. Today, the situation has changed significantly. Reasonable climate, competent mosquito vectors, and susceptible human hosts are all still present in the continental United States, and dengue viruses are frequently reintroduced by infected travelers.[138] Transmission in the U.S. is rare, however, because there is insufficient contact between infected humans, vector mosquito species, and susceptible humans to sustain transmission." *Aedes aegypti* and dengue were once prevalent in many parts of Australia, including New South Wales. As Russell *et al.* (2009)[139] point out, the current absence "is not because of a lack of a favourable climate", nor is a temperature rise of a few degrees "likely to be responsible for substantial increases in the southern distribution of *A. aegypti* or dengue, as has been recently proposed." Russell states: "of itself, climate change as currently projected is not likely to provide great cause for public health concern with mosquito-borne disease in Australia."[140]

- There are alternative explanations for the observed global increase in incidence: rapid urbanisation and international travel. Wilder-Smith and Gubler (2008)[141] also note that "the disruption of vector control programs, be it for reasons of political and social unrest or scientific reservations about the safety of DDT, has contributed to the resurgence of dengue around the world." They conclude: "population dynamics and viral evolution offer the most parsimonious explanation for the observed epidemic cycles of the disease, far more than climatic factors."
- In 1995, dengue afflicted over 4,000 Mexicans in Tamaulipas while Texas, just across the border, had only a handful of non-imported cases. The essential difference was not climate but living standards and sound public health policies.[142] Laredo, Texas (population 200,000) and Nuevo Laredo, Tamaulipas (population 290,000) are connected by bridges across the Rio Grande. After an outbreak in 1999, Reiter *et al.* (2003)[143] found "the incidence of recent cases, indicated by immunoglobulin M antibody serosurvey, was [12.3 times] higher in Nuevo Laredo, although the vector, *Aedes aegypti*, was more abundant in Laredo." Reiter *et al*. determined that "the proportion of dengue infections attributable to lack of air-conditioning in Nuevo Laredo was 55% . . . [and] if the current warming trend in world climates continues, air-conditioning may become even more prevalent in the United States, in which case, the probability of dengue transmission will likely decrease." The CDC[144] endorsed this: "Studies on the U.S.-Mexico border, for example, suggest that the restriction of transmission there is due to the limitation of contact between human hosts and mosquito vectors that comes with low housing density and the use of air conditioning and screens."
- Future solutions to dengue could include the development of effective dengue vaccines,[145] genetic modification of *A. aegypti*,[146] the sterile insect technique[147] (shown to reduce the target mosquito population by more than 90%) and the *Wolbachia* bacterium[148] which allows mosquitoes to be resistant to arboviruses such as dengue and Zika.

West Nile Virus (WNV) was first identified in a West Nile district of Uganda in 1937. It is asymptomatic in 80% of infected people but can cause severe encephalitis or meningitis in about 1 in 150 infected persons, especially the elderly or immuneocompromised. It is transmitted by a Culex species of mosquito that has bitten an infected bird (not human). Appearing in New York in 1999 and spreading across the states taking hundreds of lives, it was soon linked to climate change. [149] [150] But its rapid spread from northeast to the south and west (Fig. 9) and its decline despite warming (Figs. 10 and 11) indicates that the vector was already there and climate change had nothing to do with that.

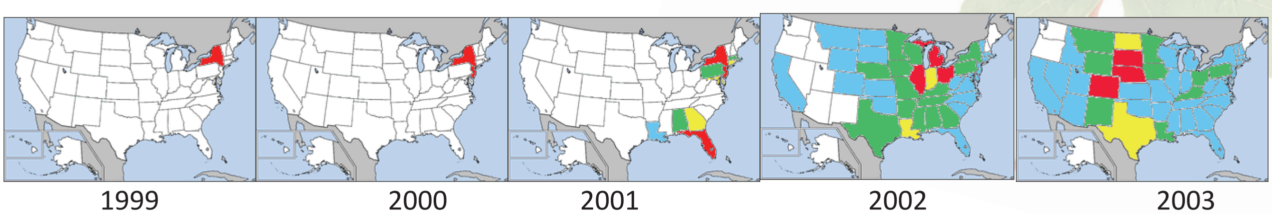
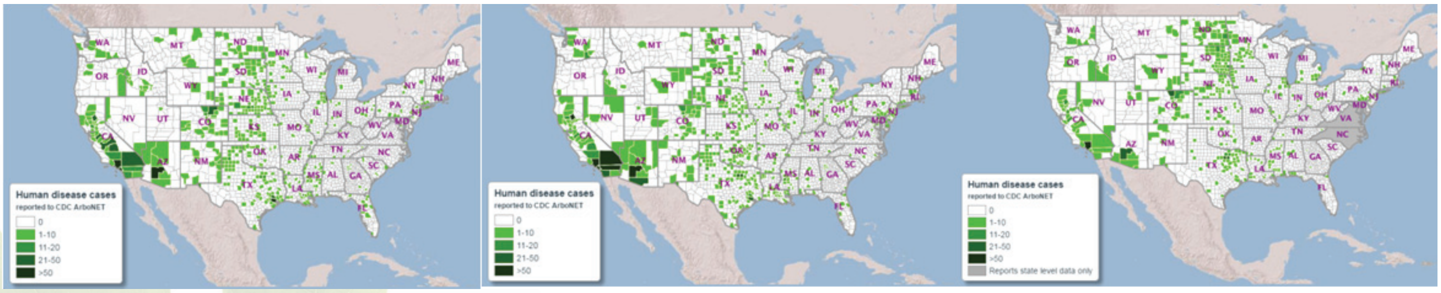


Figure 9: Progress of WNV in the U.S. 1999-2003. White 0, Blue <1%, Green1-5%, Yellow 5-10%, Red >10%



2014 2015 2016

Figure 10: WNV cases reported to the CDC 2014-2016. White 0, Green light 1-10, dark 21-50, Black >50

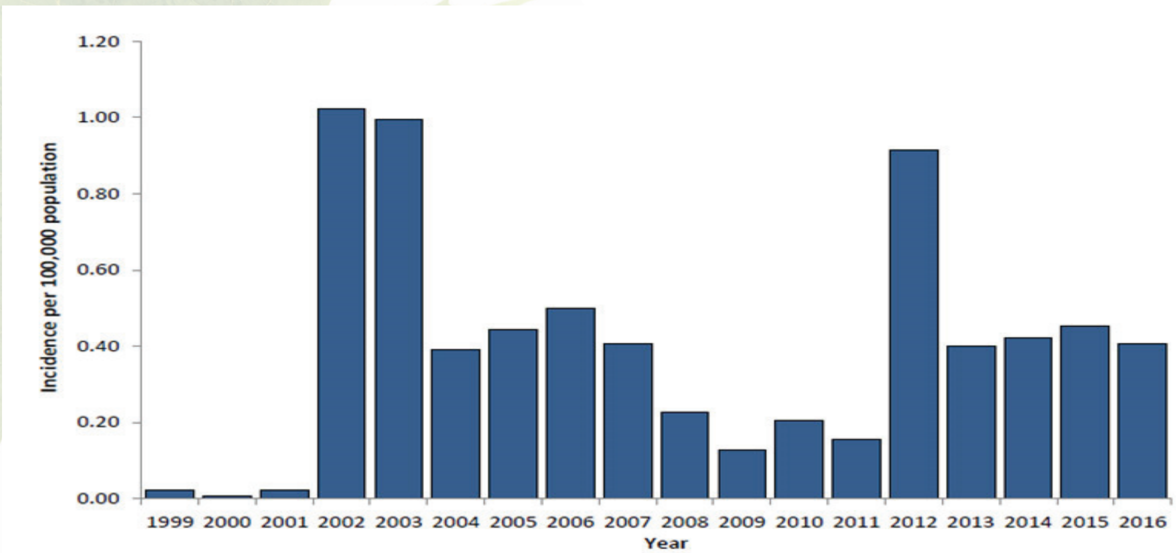


Figure 11: West Nile virus neuro-invasive disease incidence reported to CDC by year, 1999-2016

Source of Figs 9-11: CDC Cumulative Maps and Data[151] and Wikipedia[152]

Yellow fever spread from Africa to the Americas and Caribbean via the slave trade. The first recorded outbreak was in 1647 on the island of Barbados.[153] It reached New York City in 1668 and Philadelphia a year later; a 1793 epidemic in Philadelphia,[154] then the national capital, wiped out nearly 10% of its population.[155] Major outbreaks hit New Orleans in 1833 and 1853, and Memphis in 1878.[156] It spread to Europe early in the 19th century and took the lives of thousands in Gibraltar[157] and Barcelona.[158] There were even small outbreaks in France[159] and Wales.[160] Thanks to an effective vaccine[161] and stringent travel regulations, it is now confined to central Africa and South America. The story of yellow fever illustrates that science and public health policies far outweigh risks associated with global warming.

Zika virus was first identified in the 1960s in South-East Asia, where it produced nothing more than a mild illness: fever, rash and aching joints. In 2013, a Zika strain suddenly appeared in French Polynesia, then in the Caribbean and Brazil, where it exploded and resulted in over 4,000 cases of microcephaly between late 2015 and early 2016. By September 2017, there were thought to have been between three and four million cases of Zika across 84 countries, due not to "unprecedented warming" but to international air travel. A Singaporean outbreak that began in August 2016 resulted in 455 cases over three months. When Singapore's Ministry of Health and National Environment Agency quickly identified and managed infected people, eradicated mosquitoes and removed breeding sites, new cases were reduced by 48 percent within a month.[162] Public health measures can effectively control such outbreaks before climate mitigation gets its boots on! If climate action impedes proven preventive measures, it will be counterproductive.

Tick-borne encephalitis virus (TBEV), another flavivirus, is the most significant vector-borne disease in Eurasia, with a mortality rate of 1-2% and up to 24% in the Far East. Randolph and Rogers (2000)[163] studied the effect of warming on the rodent-tick vector and concluded: "fears for increased extent of risk from TBEV caused by global climate change appear to be unfounded." Because rapid cooling in autumn allows more larvae and nymphs to feed together in the following spring, the short TBE viraemia making this important for pathogen transmission, Randolph (2001)[164] suggested that TBEV transmission should be negatively affected by a warmer climate. Reported cases in Estonia and Lithuania[165] declined during the warm 1998 El Niño and were even lower in 1999. The end of Soviet rule and subsequent socioeconomic transition produced conditions favourable for transmission.[166] Randolph concluded: "there is increasing evidence from detailed analyses that rapid changes in the incidence of tick-borne diseases are driven as much, if not more, by human behavior that determines exposure to infected ticks than by tick population biology that determines the abundance of infected ticks . . . the evidence is that climate change has not been the most significant factor driving the recent temporal patterns in the epidemiology of tick-borne diseases."[167]

Lyme disease was first diagnosed in 1975 in Old Lyme, Connecticut,[168] from whence it derived its name. It is the most common tick-borne human disease, with an estimated annual incidence of 300,000 in the United States[169] and at least 85,000 in Europe.[170] It is caused by the spirochete bacteria, *Borrelia burgdorferi* and sometimes by *Borrelia mayonii*.[171] It is transmitted in the eastern United States and parts of Canada by the tick, *Ixodes scapularis*, and on the Pacific Coast by *I. pacificus*.[172] As these ticks like habitats with at least 85% humidity and need temperatures over 7 °C (45 °F) during host questing in spring,[173] the northeast United States is especially suitable (Fig. 12).

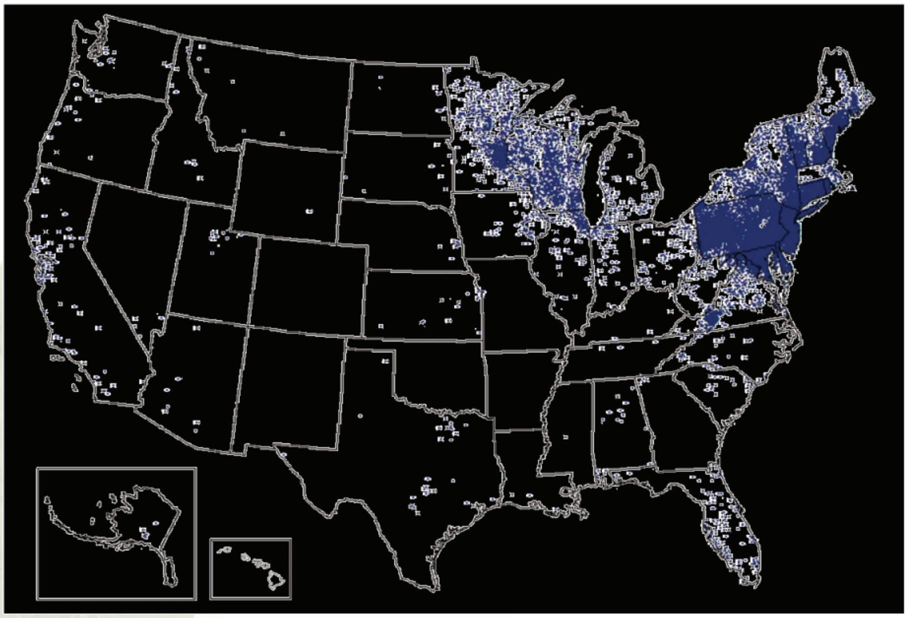


Figure 12: Reported cases of Lyme disease in the United States in 2016. Source: CDC Lyme Resources Brochure[174]

The impact of climate change on Lyme disease appears to be complex. Subak (2003)[175] found a correlation between warmer winters and the incidence of Lyme disease the next summer, perhaps because mild winters enhance survival of the ticks' primary host, the white-footed mouse. Warm dry summers, on the other hand, are associated with a reduced incidence, perhaps because of reduced survival of both mouse and *Ixodes* nymph.[176] The number of reported cases of Lyme disease appears to have peaked in 2009, despite further warming (Fig. 13).

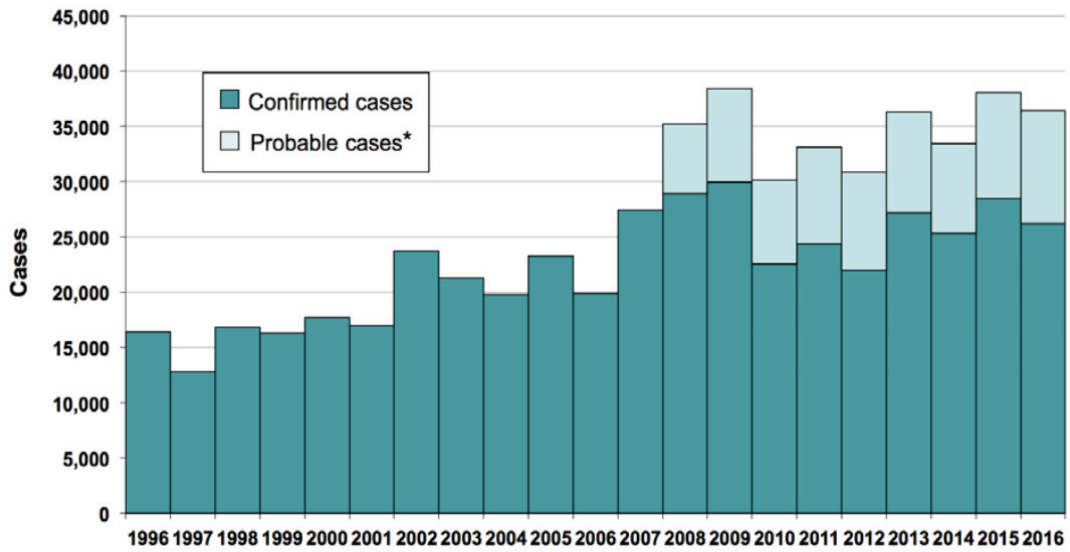


Figure 13: Reported cases of Lyme disease in the U.S., 1996-2016. Source: CDC Lyme Resources Brochure[177]

Modelling by Brownstein *et al.* (2005):[178] "generated the current pattern of *I. scapularis* across North America with an accuracy of 89% ($P < 0.0001$). Extrapolation of the model revealed a significant expansion of *I. scapularis* north into Canada with an increase in suitable habitat of 213% by the 2080s. Climate change will also result in a retraction of the vector from the southern U.S. and movement into the central U.S." As their modelled transmission zone migrates northwards into Canada over the next 70 years, it retreats from Florida and Texas, and the population exposed to Lyme actually diminishes, by 28% in the 2020s, by 12.7% in the 2050s and by 1.9% in the 2080s. The connection between suitable *I. scapularis* and deciduous forest is so strong that the authors state: "recent emergence of Lyme disease throughout the northeastern and mid-Atlantic states has been linked to reforestation". The motor car may thus have contributed to the emergence of Lyme disease by converting numerous redundant horse-paddocks into woodlands and by fertilising them with carbon dioxide.

In Europe and Asia, the vectors of Lyme borreliosis (LB) are *I. ricinus* (Europe) and *I. persulcatus*.[179] Like its North American cousin, *I. ricinus* prefers forest to open land and deciduous to conifer.[180] Late 20th century warming has been linked to ticks spreading into higher latitudes and altitudes (observed in the Czech Republic[181]) and to higher incidences of LB,[182] though distorted by better reporting over time in most regions. Moreover, the incidence of LB actually declined after 1995 in the Czech Republic and Lithuania.[183] In a 2006 WHO publication[184] on Lyme borreliosis in Europe, Elisabet Lindgren and Thomas G.T. Jaenson state:

> The impact of climate variability on disease occurrence is more complex than the effects that the climate may have on the distribution and population density of the vectors. Studies on the effects of long-term climate variations on tick-borne disease prevalence are affected by several scientific problems. Data vary between places and over time owing to differences in awareness, surveillance, and diagnostic methods, which so far have made longterm studies on LB difficult to perform.

As with TBEV, the impact of climate change on the vectors and transmission of Lyme disease is complex and uncertain. The focus should be on educating the public, early diagnosis and treatment rather than climate mitigation.

Leishmaniasis, from over *20 Leishmania* species of protozoa parasite, is transmitted by an infected female sandfly, with over 50 species of the genus *Phlebotomus* in the Old World and genus *Lutzomyia* in the New World. The main animal reservoirs include rodents, dogs, wild cats, jackals, foxes, sloths, hyraxes, and other carnivores. It is endemic in 88 countries across Africa, Asia, Europe, and North and South America, infecting up to a million people and killing up to 30,000 annually, mainly among the poorest people on Earth.[185] It is associated with malnutrition, population displacement, poor housing, a weak immune system and lack of financial resources. It is also linked to environmental changes such as deforestation, building of dams, irrigation schemes, and urbanization.

The disease manifests in three forms: visceral, cutaneous, and mucocutaneous.[186] The most common form is cutaneous leishmaniasis which occurs in the Americas, the Mediterranean basin, central Asia and the Middle East, and has been increasing in Egypt.[187] Visceral leishmaniasis (kala-azar) is highly endemic in Sudan, is strongly associated with malnutrition and fatal in 95% of untreated cases. It is thought to have spread from there to the Indian subcontinent and the New World.[188] Over 90% of mucocutaneous leishmaniasis occurs in Ethiopia, Bolivia, Brazil and Peru. In North America, leishmaniasis is endemic in Mexico and Texas and has begun to expand its range northward (Fig. 14). Models indicate that climate change may extend the risk of human exposure northwards, even into parts of southern Canada.[189]

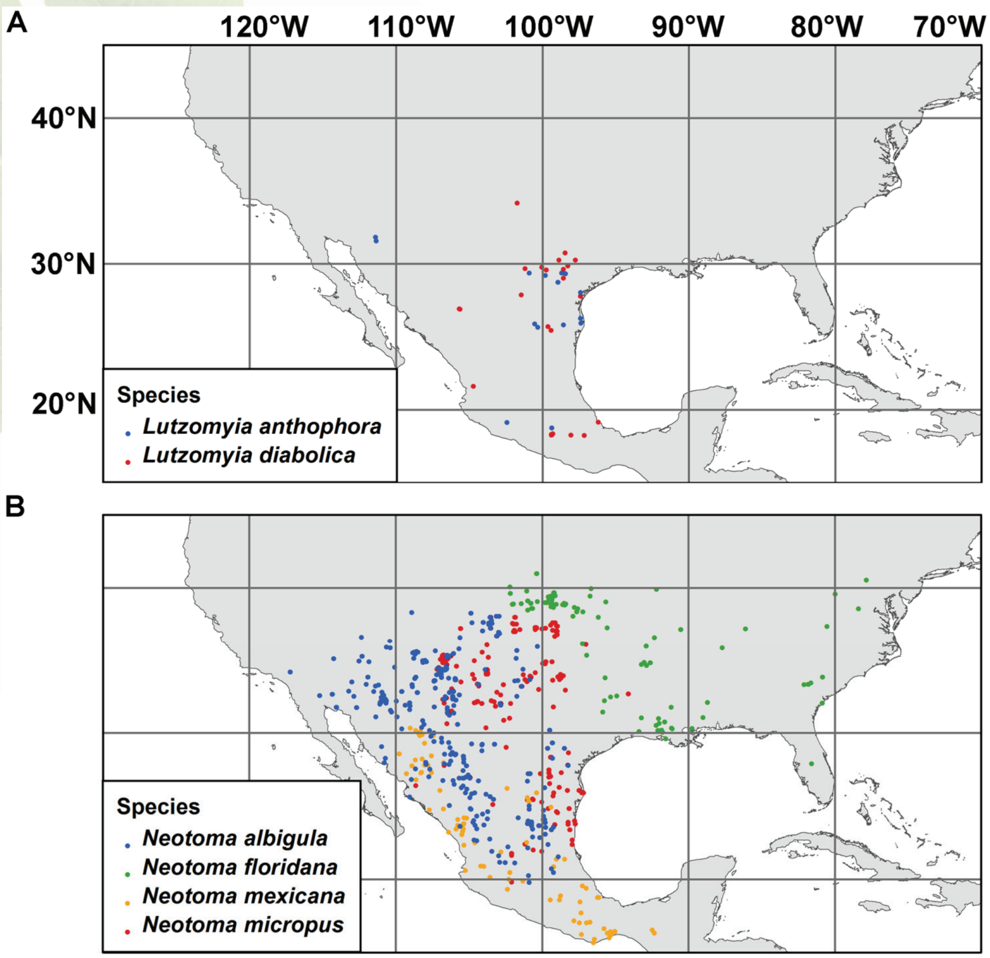


Figure 14: Vector and reservoir data points in North America (2009 data).
A: Both vector species. B: All four reservoir species. Source: Gonzalez *et al.* (2010)[190]

Such modelling, of course, is as uncertain as the climate modelling on which it is based. It also assumes that the United States will be no more effective than African nations in preventing the spread of this disease and its vectors.

Extreme Weather Events

The deadliest natural disasters include hurricanes/typhoons/cyclones, storms/tornadoes, floods, droughts, heatwaves and wildfires. It is claimed that anthropogenic climate change is making these worse and thus putting more lives at risk.

Cyclones in the Southern Hemisphere are the same as North Atlantic hurricanes and Northwest Pacific typhoons except that they spin clockwise. Wind (120-300+ km/h), storm surge and flooding rain make these one of the deadliest natural disasters. A tropical cyclone in 1970[191] killed an estimated 300,000 people in what is now Bangladesh. The deadliest Atlantic hurricane was probably the Great Hurricane of 1780,[192] which took about 22,000 lives. Major hurricanes hit New York City in 1815[193] and 1821,[194] and another in 1893.[195] Atlantic hurricane activity actually declined from 1800 and was unusually quiet during the period 1970-1995 (Fig. 15). In 2013, no major hurricane made landfall for the first time in 45 years, and hurricanes were the fewest in number since 1982.

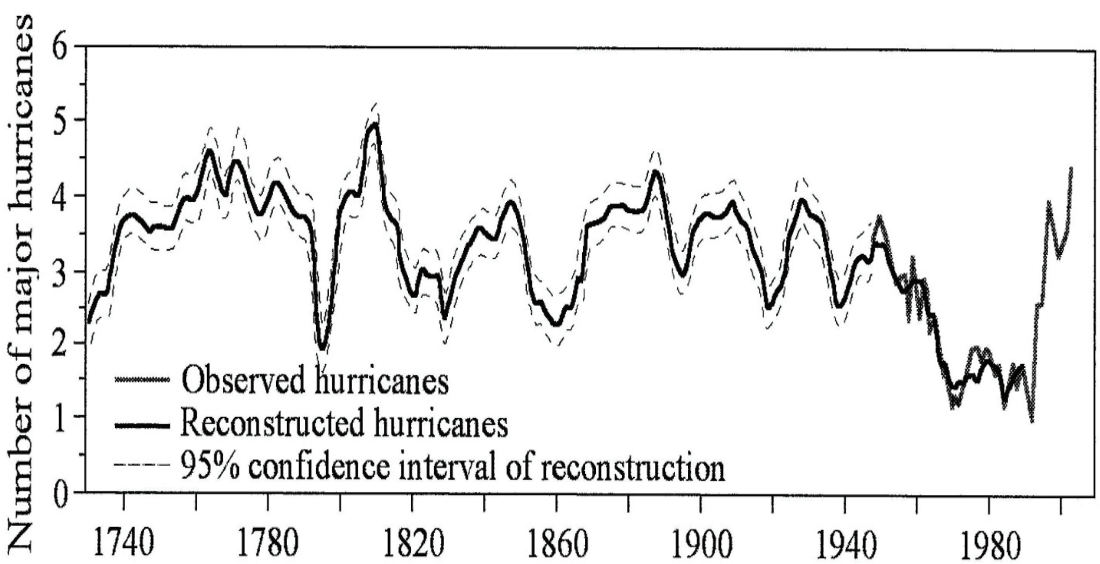


Figure 15: Annual Number of Major Atlantic Basin Hurricanes, 1730-2005: Reconstructed from coral and plankton sediments in the Caribbean Sea and Observed. Source: Nyberg *et al.* (2005)[196]

Water vapour reaching high altitudes and precipitating as cyclonic rain contains a higher proportion of oxygen-16 isotope, which is lighter than oxygen-18. Nott *et al.* (2007)[197] used this to analyse cyclonic activity over 800 years from stalagmites in a Chillagoe cave in North Queensland and found that the most intense cyclones preceded white settlement (Fig. 16). The frequency and intensity of Australian cyclones since 1970 is shown in Figure 17.

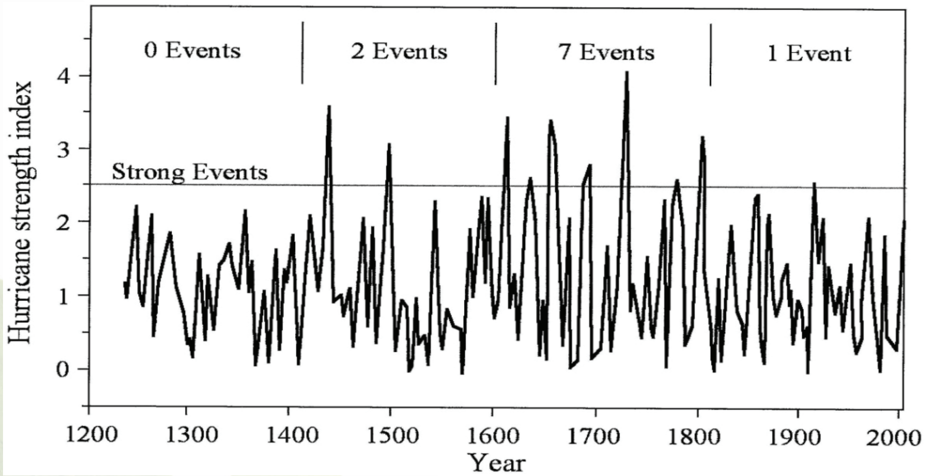


Figure 16: Strength Index of Tropical Cyclone Events in North Qld., 1226-2003
Source: Nott *et al.* 2007.

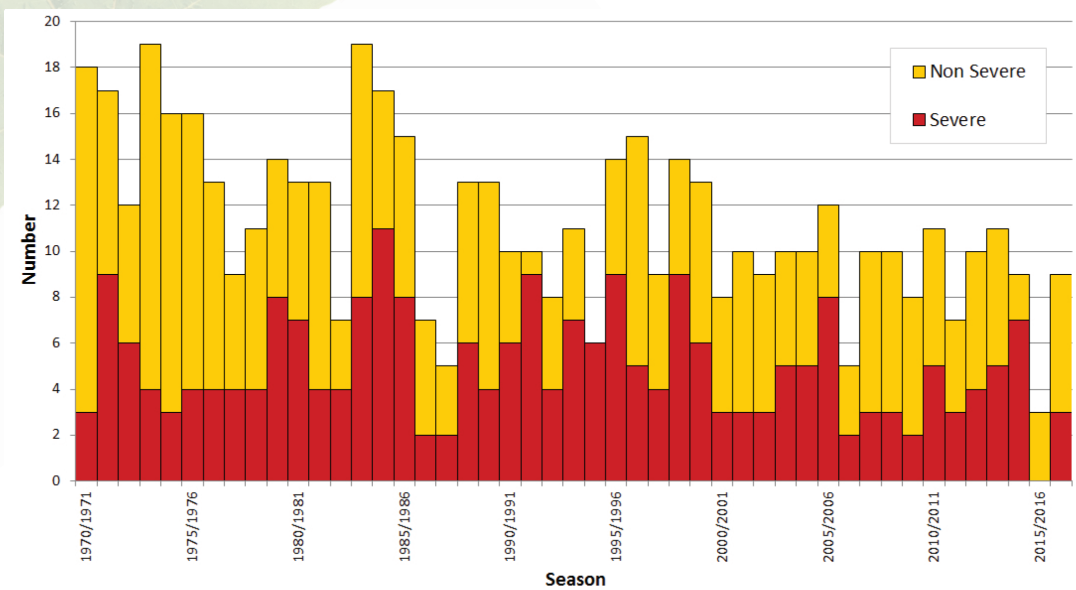


Figure 17: Number of severe and non-severe tropical cyclones in Australia, 1970-2017. Severe tropical cyclones are those with a minimum central pressure less than 970 hPa. Source: Bureau of Meteorology[198]

Haig and Nott (2016)[199] later developed “a new tropical cyclone activity index spanning the last 1500 years” and found “that in addition to other well-known climate indices, solar forcing largely drives decadal, interdecadal, and centennial cycles within the tropical cyclone record.”

Cyclones have caused over 2,100 deaths in Australia since 1839.[200] Category 5 Cyclone Mahina[201] was Australia’s deadliest natural disaster, killing over 300 people in 1899. Thanks to better forecast and warning systems, and to improved building codes in cyclone-prone regions, loss of life from cyclonic activity is now rare – not a single death in 2011 from Category 5 Cyclone Yasi.[202] While deaths have dramatically declined, damages have increased, but not due to climate change. According to the World Meteorological Organization,[203] "the recent increase in societal impact from tropical cyclones has largely been caused by rising concentrations of population and infrastructure in coastal regions." After normalizing the mainland U.S. hurricane damage during 1900-2005 to 2005-values, Pielke *et al*. (2008)[204] found no trend in damages. They were notably low during the 1970s and 1980s. The 1926 Miami hurricane[205] caused the most damage: $157 billion normalized.

Typhoons[206] account for nearly a third of the world's tropical cyclones. The deadliest was Typhoon Nina which took nearly 100,000 lives in China when flooding caused 12 reservoirs to fail in 1975.[207] The most intense were Typhoon Tip in 1979,[208] with wind speeds of up to 310km/h before making landfall in the central Philippines, and Typhoon Haiyan in 2013,[209] with wind speeds up to 314km/h. The most active typhoon season was in 1964, with 39 typhoons and tropical storms, and the least active was 2010, with 21 typhoons and tropical storms. There were 11 super typhoons in 1965 and only 5 in 2013. The 4-year period from 1964 to 1967 saw an average of 13.5 tropical storms, 15 typhoons and 7 super typhoons per year. The next most active period in the 1990s saw an average of 12 tropical storms, 15 typhoons and 5 super typhoons per year.[210]

Storms forming over land also inflict casualties. The deadliest[211] killed 1,300 people in the Manikganj District of Bangladesh in April 1989. A single lightning strike killed 21 people in a hut in present-day Zimbabwe in December 1975, and hail the size of cricket balls killed 246 people near Moradabad, India, in April 1888.[212] A similar hailstorm hitting Sydney[213] on 14 April 1999 inflicted damages of $1.7 billion (over $4 billion today) but killed no one; the essential difference was wealth.

An analysis of hailpads in France from 1990 to 2010 by Hermida *et al.* (2013)[214] showed an upward trend in 154 (significant in 10%) and a downward trend in 177 (significant in 17%). Changnon and Changnon (2000)[215] assessed hail-day trends over a 100-yr period, 1896–1995, from carefully screened records of 66 stations across the United States, and found five types of 20-year fluctuation. They state:

> One present in the Midwest had a peak in hail activity in 1916–35 followed by a general decline to 1976–95. Another distribution had a midcentury peak and was found at stations in three areas: the central high plains, northern Rockies, and East Coast. The third distribution peaked during 1956–75 and was found at stations in the northern and south-central high plains. The fourth temporal distribution showed a steady increase during the 100-yr period, peaking in 1976–95, and was found in an area from the Pacific Northwest to the central Rockies and southern plains. The fifth distribution found at stations in the eastern Gulf Coast had a maximum at the beginning of the century and declined thereafter. The 100-yr linear trends defined four regions across the United States with significant up trends in the high plains, central Rockies, and southeast, but with decreasing trends elsewhere in the nation. These up trends have occurred in areas where hail damage is greatest, and the trends matched well with those defined by crop-hail insurance losses and those found in studies of thunderstorm trends. The national average based on all station hail values formed a bell-shaped 100-yr distribution with hail occurrences peaking in midcentury.

Tornadoes in the U.S. have decreased in severity since recording began in 1954 (Fig. 18). NOAA states: "the increase in tornado reports over the last 54 years is almost entirely due to secular trends such as population increase, increased tornado awareness, and more robust and advanced reporting networks."[216] Tornado activity increases with La Niña events, when the eastern Pacific Ocean is cool, and decreases during El Niño events.[217] NOAA reported 2011 as being the most costly year (over $28 billion in damages) and the most deadly (with 551 fatalities) while 2016, the warmest year ever on record,[218] had the fewest tornadoes ever on record. There were 34 tornado-related fatalities in 2017.

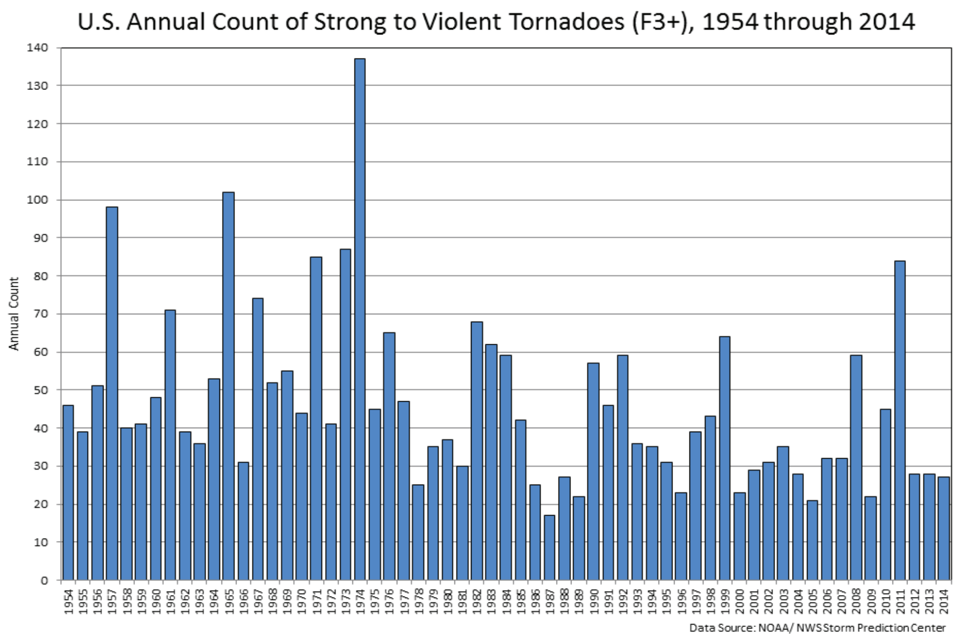


Figure 18: Annual number of strong tornadoes across the United States, 1954-2014. Source: NCDC/NOAA[219]

By reducing daytime and latitudinal temperature ranges, CO_2 may actually reduce the pressure differentials that drive extreme weather events. Rendering them less deadly requires a sound economy.

Floods take many lives and impact the health of survivors, often long after the event. The world's deadliest flood occurred in 1332-3 when China's Huang He (Yellow) River killed seven million people. The next deadliest floods occurred in 1887 and 1931 when the same river killed between a million and four million people.[220] There were approximately 100,000 flood fatalities in England and the Netherlands in 1099, about 80,000 in the Netherlands when the "Great Storm" broke a dike in 1287, and another 10,000 from a similar incident in 1421. In 18th century Europe, late thaw ice jams blocked swollen rivers and burst dikes in the Netherlands.[221] The highest flood risk in Germany's River Werra was in the 1700's.[222] All but two of the 56 major floods affecting Florence since 1177 occurred before 1844.[223] Flooding of the river Vltava in the Czech Republic decreased over the last century.[224] All but two of Australia's top ten worst floods[225] occurred before 1975. During the 19th century, Brisbane had as many floods in 53 years as in the last 125 years. The highest flood was in 1841, followed closely by the prolonged and widespread flood of 1893 (Fig. 19).

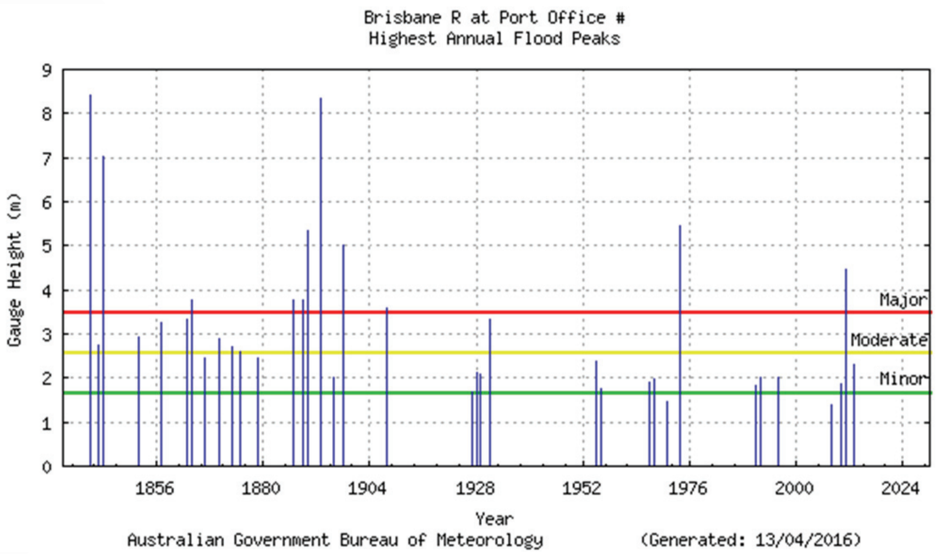


Figure 19: Brisbane River heights in metres, 1840-2016. Source: Australian Bureau of Meteorology[226]

A global analysis of nearly 200 rivers revealed that flows over the last century were unchanged in the majority, increasing in 27 and decreasing in 31.[227] This is also true for those rivers with observations stretching back much further in time.[228] The IPCC's AR5[229] agrees: "there continues to be a lack of evidence and thus low confidence regarding the sign of trend in the magnitude and/or frequency of floods on a global scale."

It is estimated that more than 59,000 flood fatalities occurred worldwide between 2005 and 2014,[230] the vast majority in Asia, especially among women.[231] Haynes *et al*. (2016)[232] analysed 1,859 Australian flood fatalities from 1900 to 2015 and found a dramatic decline (Fig. 20) despite higher rainfall (Fig. 21). Ashley and Ashley (2008)[233] found no statistically significant trend in fatalities over the period 1959-2005 in the United States (Fig. 22).

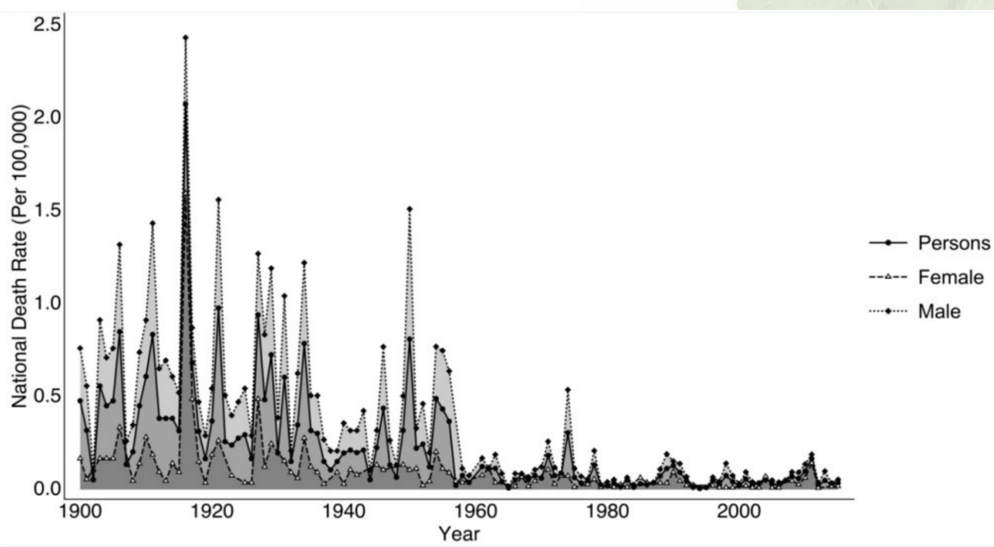


Figure 20: Australian flood fatality rate from 1900 to 2015. Source: Haynes *et al.* (2016)[234]

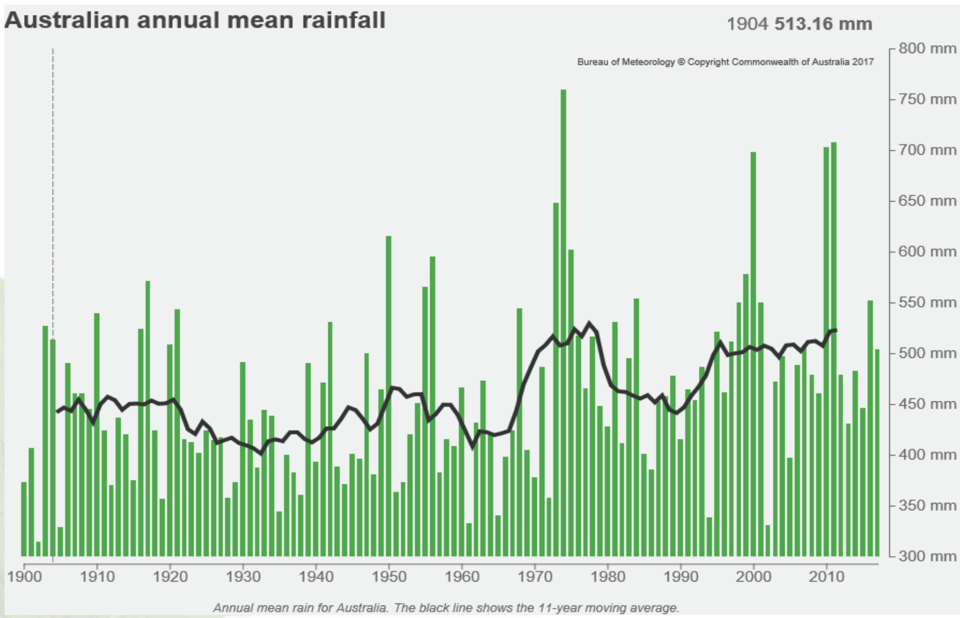


Figure 21: Annual mean rainfall across Australia, 1900-2017. Source: Australian Bureau of Meteorology[235]

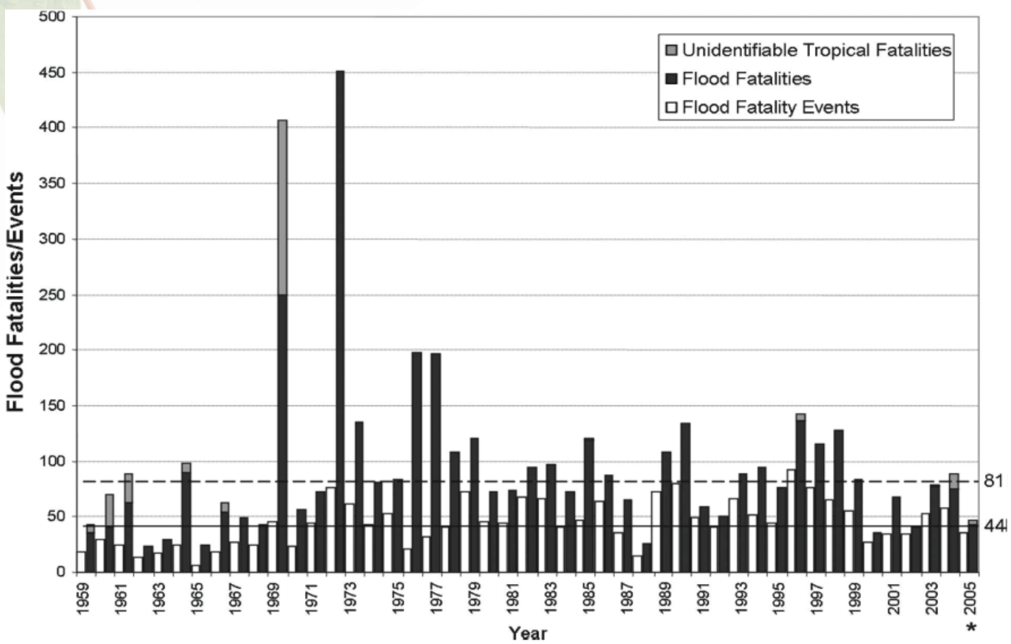


Figure 22: Flood fatalities in the continental United States, 1959-2005. Black bars represent deaths due strictly to flooding for all event types in the study. Gray bars represent deaths due to tropical systems but not to flooding alone. Light gray bars represent deadly events. The dashed horizontal line represents yearly fatality median, and the nondashed horizontal line represents yearly fatality event median. The asterisk indicates that 2005 data are preliminary and do not include Hurricane Katrina fatalities from Louisiana. Source: Ashley and Ashley 2008[233]

Water security during flooding is important. Leptospirosis is a zoonotic disease acquired from infected animals, soil or water, especially flood water contaminated with rat urine. Globally, there are about a million severe cases and 60,000 deaths reported annually. Recent unprecedented outbreaks have been blamed on climate change, but the main reason is population growth plus poverty resulting in urban slums in developing countries.[236]

The Australian evidence indicates that the solution to flooding is not climate-mitigation but better infrastructure, warning systems, evacuation centres, rescue services etc. While flood casualties have been declining, health problems associated with dislocation and economic losses have been increasing due to population growth, especially along waterways. Flooding also has much more to do with altered land use and loss of flood-mitigating wetlands than with fossil fuel emissions. Bjorn Lomborg put it simply and starkly: "a dollar spent on flood management will reduce flooding 1,300 times better than a dollar spent on Kyoto."[237]

Drought in the American west is often attributed to climate change, but accurate records of precipitation going back to 1895 indicate no significant trend in either the Southwest or Northwest Regions.[238] Meko *et al.* (2007)[239] demonstrated a robust relationship between tree-rings and observed stream flow in the Colorado River from 1905. Using these as proxies for stream flows back to 762CE, they found many severe droughts, the worst being in the 12th century (Fig. 23).

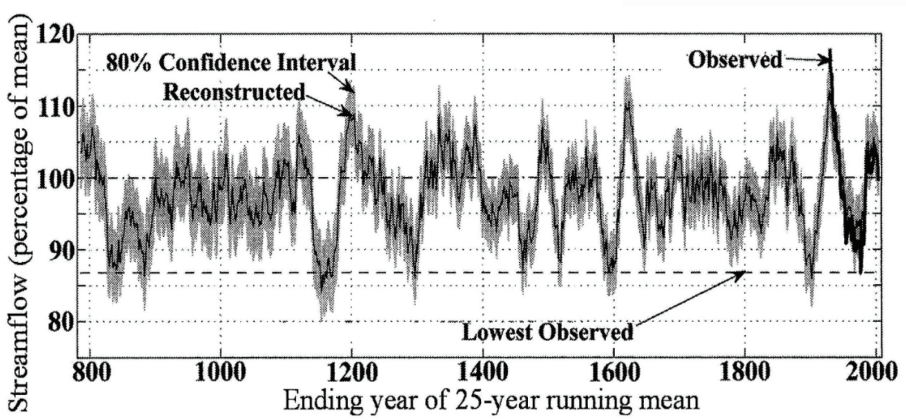


Figure 23: Colorado River stream flow, Observed: 1905-2005 & Reconstructed from Tree Rings: 762-2005
Source: Adapted from Meko et al, 2007.

The Sahel, covering 17 North West African countries, has a population of around 309 million, growing by about 3% per year. Devastating droughts there have been blamed on climate change.[240] Rainfall over most of the Sahel declined at least 30% from the 1950s to the 1980s, but the 1950s were unusually wet, primarily because the Northern Hemisphere was warmer than the Southern Hemisphere; rainfall normalized as hemispheric temperatures equalized in the 1980s and 1990s.[241] A GFDL report,[242] updated 2 February 2018, concluded: "the drying from the 1950's to the 1980's is unlikely to be primarily forced by increasing greenhouse gases in the atmosphere." Climate models indicate that wet regions will become wetter and dry regions drier,[243] but Sun *et al.* (2012)[244] found that from 1940 to 2005, wet areas got drier while dry areas got wetter. Another study found no difference.[245]

As atmospheric CO_2 increases, leaf stomata density and water loss decrease;[246] thus rendering plants more drought-tolerant.[247] As CO_2 increased by 15% from 1982 to 2012, vegetation cover increased by 11% in arid areas.[248] Konzmann *et al.* (2013)[249] estimated that global irrigation demand will decline by about 17% by the 2080s, due to a combination of beneficial carbon dioxide effects on plants, shorter growing periods and regional precipitation increases. Regarding water availability, Wiltshire *et al.* (2013)[250] estimate that the net global population at risk of high water stress will increase from 2.6 billion in 2000 to 4.1 billion in the 2080s due to population growth, but to 3.2 billion under the IPCC's A1FI scenario (the one with the fastest warming), and to 2.9 billion when the benefits of CO_2 are factored in; the higher the CO_2 and the warmer the scenario, the greater the reduction in the population at risk of water stress.

Heatwaves are expected to increase in a warming world. Record-breaking heatwaves in Europe (2003[251], 2007[252]) Russia (2010[253]) the U.S. (2011[254]) Australia (2009[255], 2013[256]) and globally[257] have been linked to the human influence on climate, but this is far from certain. During the deadly 2003 European heatwave, for example, most of the planet was normal or cooler than normal at the time (Fig. 24). By comparison, 30% of the planet was 2 standard deviations (SDs) above normal (5% of it 3 SDs above) during the El Niño of 1998.

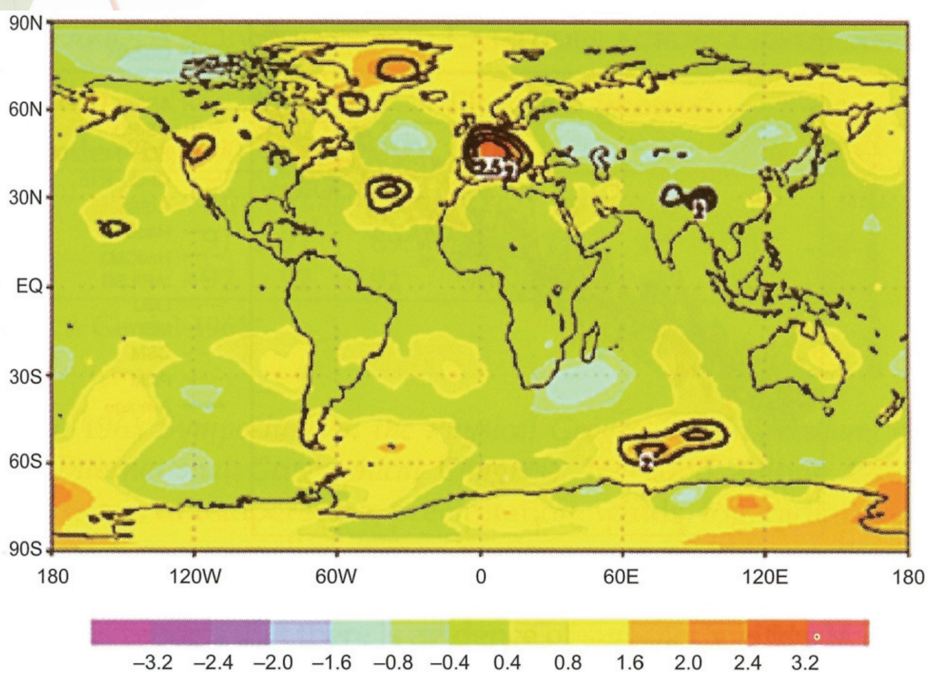


Figure 24: Global tropospheric temperature anomalies, June-August 2003. Source: Chase *et al.* (2006)[258]

Due to reduced soil moisture after another strong El Niño event, the Australian summer of 2016-17 was exceptionally warm, but only in the eastern states; Western Australia and the Northern Territory experienced an unusually cold summer and one of the wettest on record (Fig. 25). While Canberra reached 40^{o}C on 9 February 2017, Perth reached just 17.4^{o}C, its coldest February day on record. Twelve days later, Canberra had its coldest February morning on record! Heatwaves are weather events.

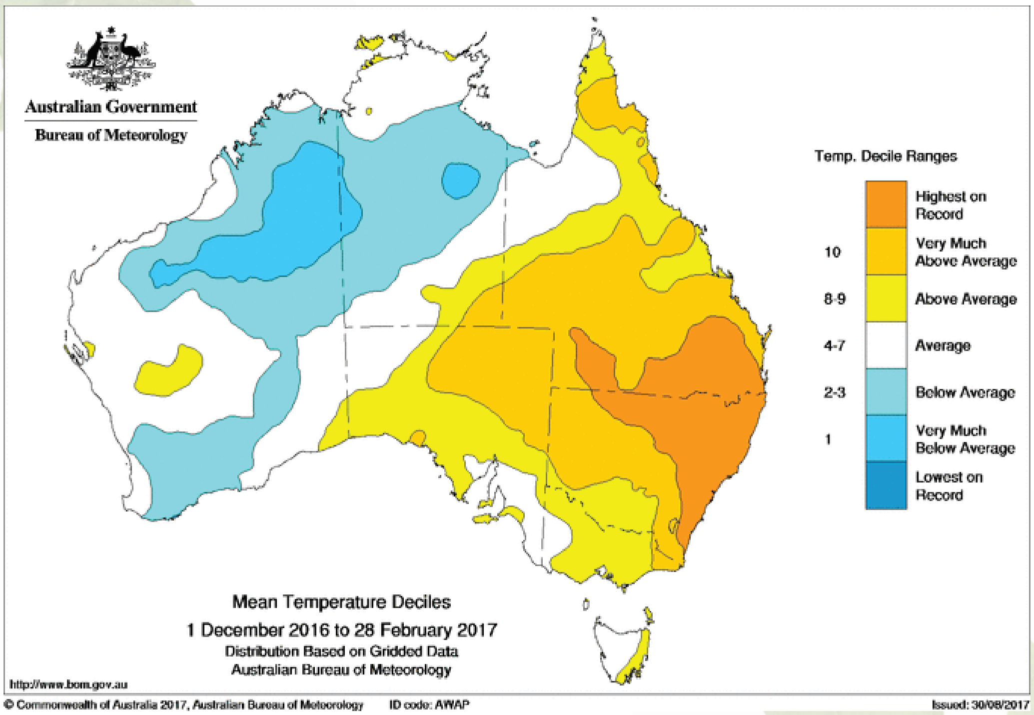


Figure 25: Mean Temperature Deciles for the 2016-17 Australian Summer. Source: Australian BOM

The worst heat wave in New South Wales since white settlement was in January 1896 when the maximum temperature was 102^{o}F (38.9^{o}C) or above for 24 days straight, 120^{o}F (49.9^{o}C) in the shade at Bourke, and 109^{o}F (42.8^{o}C) at midnight at Brewarrina.[259] Hundreds died and the hospitals were crowded with victims.[260] In the United States, a 10-day heatwave in the August of that year killed nearly 1,500 people,[261] mostly manual labourers in New York City.[262] Another very prolonged heatwave across the eastern states in 1901 killed 9,500 people, making it easily the most destructive heatwave in U.S. history.[263] The 1936 North American heatwave during the Dust Bowl decade set record temperatures across 14 states, reaching 49^{o}C in Steele, North Dakota.[264] It caused catastrophic human suffering and killed at least 5,000 people. The summer-long heatwave across the Midwest of the USA in 1954 ranks as the hottest in 11 states from 1895 to 2009 (Fig. 26), reaching 117^{o}F (47.2^{o}C) on 14 July in East St Louis. Nancy Westcott (2011) analysed temperature records there from 1845 to 2009 and found a ***reducing*** trend over the 20th century. The UK had severe heatwaves in 1906, with temperatures reaching a September record of 35.6^{o}C,[265] and in 1911, with temperatures reaching an August record of 37.1^{o}C.

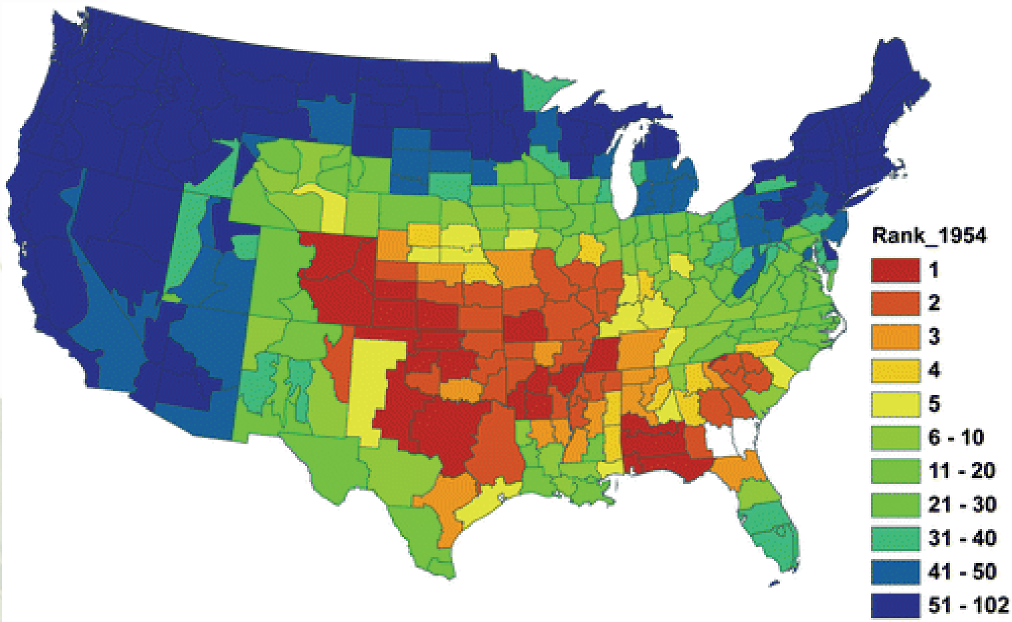


Figure 26: Rank of the June–September 1954 heat wave based on National Climatic Data Center (NCDC) climate division temperature data for the years 1895–2009. Source: Westcott (2011)

Urban heat amplifies heatwaves. Large cities can be as much as 11°C warmer than the surrounding countryside.[266] Torok (2001)[267] found minimum temperatures in inner city Melbourne to be significantly higher than those in the suburbs. Edward Long (2010)[268] compared NCDC rural and urban temperature datasets and found that the raw rural and urban data correlated very closely until 1965, when the urban data escalated rapidly. England's urban population jumped from 17% to over 70% during the 19th century. The global urban population was about 30% in 1950 and 50% in 2008, and is expected to reach 70%[269] by 2050. Australia and the U.S. are now nearly 90% urban. Urban heat can be mitigated more effectively and economically than can greenhouse warming. Watts and Barrins (2014)[270] describe how smart urban design can create cool refuges in cities. The greening of cities and cooling water features require adequate water resources, heatwaves often being associated with drought. We can learn many lessons from Cape Town.

Those at risk during heatwaves include the elderly, especially those living alone, people with heart or lung disease, pregnant or nursing mothers, babies and young children. Heat-tolerance is reduced by obesity[271] and increased by aerobic fitness.[272] Unlike cold spells, the mortality from heatwaves is reduced by acclimatisation.[273] Whereas mortality remains higher for weeks after a cold spell, it drops rapidly and dramatically after a heatwave, indicating that most of those who die from short-term heat exposure were close to death.[274] This "harvesting effect" has been demonstrated both in Europe[275] and in the United States, so much so that "there is virtually no lasting impact of heat waves on mortality."[276]

The excess mortality during the unusually hot European summer of 2003 was estimated at over 70,000.[277] There were confounding variables: elevated atmospheric concentrations of ozone and particulate matter less than 10µm diameter (PM_{10}) accounted for 21-38% of deaths attributed to temperature in the UK[278] and for 33-50% of those in the Netherlands.[279] In France, the death rate was also higher than that expected from temperature alone.[280] Most of the 15,000 excess deaths occurred during the month-long August vacation during which there was a relative lack of care for the isolated and vulnerable, especially elderly females. The French Directorate General for Health then set up a National Heat Wave Plan which included a system for real-time surveillance of health data, compilation of scientific recommendations on the prevention and treatment of heat-related diseases, air-conditioning equipment for hospitals and retirement homes, emergency plans for retirement homes, city-scale censuses of the isolated and vulnerable, visits to those people during the alert periods, a warning system and repeated preventive message broadcasting by the media. When France experienced another severe heatwave in July 2006, Fouillet calculated nearly 4,400 fewer deaths than expected. Modern forecast and warning systems have been shown to be very effective in preventing heat-related deaths.[281] Compared to combating global warming, such adaptation measures are reliable, relatively cheap and rapidly effective in reducing mortality.

The 1954 U.S. heatwave was worse than the 1936 heatwave in intensity, duration and extent, but killed fewer than a fifth as many people,[282] largely because the home window air conditioners introduced after World War II became popular, as did fans, refrigerators, ice, cold drinks and cool clothing during the summer of 1954. While the global population has tripled since the 1920s, the global mortality from all weather-related natural disasters declined by 99%, from 242 per million to just 3 per million people per annum, thanks to improved economies and technologies.[283] Instead of combating climate change to moderate heatwaves, the focus should be on evidence-based mitigation of urban heat and on proven adaptation measures.

Wildfires shaped the Australian landscape for 65 million years before indigenous people began using fire to do so about 45,000 years ago.[284] Large parts of northern Australia burn every year or two during the dry season (winter and spring) after fuel accumulates during the summer monsoon season. As much as 35% of high-rainfall areas can burn in a typical year.[285] Southern Australia experiences far fewer fires with a peak season in the summer and autumn, but they are much more deadly. More than 800 Australians have died in bushfires since 1850,[286] the most in Victoria followed by NSW and Tasmania.[287] Of the 173 Victorians killed on ‘Black Saturday’ in February 2009, 44% were under 12 or over 70 or unwell at the time.[288]

Unlike heatwaves, forest fires can have remote and protracted health consequences. The toxic and potentially carcinogenic smoke can impact health hundreds of kilometres away.[289] Particulate matter smaller than 2.5 microns ($PM_{2.5}$) from wildfires and wood heaters is far more toxic to the respiratory system than equivalent concentrations of $PM_{2.5}$ from background urban sources.[290] Johnson *et al.* (2012)[291] estimated that the smoke from wildfires kills over 300,000 people globally, mostly in Africa and Asia. On days when air pollution from surrounding bushfires is severe, cardiac arrests in Melbourne jump nearly 50%,[292] and Sydney’s overall mortality rate increases by about 5%.[293] Most affected are infants, the elderly and those with chronic heart and lung conditions,[294] especially asthma and COPD.[295] Wildfires in catchment areas can temporarily render the water unfit for human consumption[296] and reduce runoff by as much as 50% as trees regenerate over subsequent years or decades.[297] Bushfires can also adversely impact the mental health of fire-fighters[298] and survivors, especially those losing loved ones, livelihood and/or property, often for months and sometimes for years after the fire.[299]

The burning question, of course, is whether wildfire activity is increasing as a result of anthropogenic warming. Although the area burned from 1997 to 2011 decreased globally,[300] increased forest fire frequency and/or duration of fire season has been observed in Africa,[301] South Africa,[302] Australia,[303] Alaska,[304] Canada,[305] western USA,[306] Russia[307] and Spain.[308] Factors influencing wildfires include the prevailing weather (hot dry winds), topography, fuel load (dry, oil-rich vegetation, altered ecosystems) and ignition source (natural or human). The human impact is also influenced by controlled burning, fire-breaks, clearing around dwellings, fire protection, warning systems, fire-fighting capabilities and demographics; most buildings affected by major bushfires in Australia are within 100m of bushland, and many back right onto it.[309] Increasing atmospheric CO_2 levels are thought to increase wildfires by increasing fuel load via warmer and wetter growth conditions and by CO_2 fertilisation,[310] increasing combustibility via reduced precipitation and increased temperatures,[311] and by increasing ignition via lightning strikes.[312]

It is much more nuanced, however: increased atmospheric CO_2 benefits trees more than grasses, which dry out and burn faster. Ecosystem models are poor at simulating local variations in rainfall, tend to overestimate the growth response to precipitation, and don't include plant diversity, ground water, mineral composition of the soil, forest management, grazing, changes in cultivation practices and varieties, irrigation and disturbances such as storms and insect attacks, which together contribute the most variation in global greening.[313] Only a small minority of wildfires are ignited by lightning strikes, and this is thought to increase by perhaps 5-6% per degree (1°C) of warming.[314] Balch *et al.* (2017)[315] evaluated over 1.5 million government records of wildfires in the U.S. from 1992 to 2012 and found that humans accounted for 84% of them, that the human-caused fire season was three times longer than the lightening-caused fire season. Whereas those started by humans were dominant across most of the U.S. (5.1 million km^2), those caused by lightning were dominant across only 0.7 million km^2, primarily the sparsely populated mountainous areas of the western United States. Many wildfires, such as California's Wine Country fires in 2017, are started by downed power lines in high winds.[316] A Royal Commission[317] into the 2009 Black Saturday bushfires in Victoria concluded:

> Nine of the 15 fires the Commission examined were started as a direct or indirect result of human activity; five were associated with the failure of electricity assets, and the causes of four were thought to be suspicious. Broader data suggest that about one-third of bushfires in Victoria might be lit by people acting with mischievous or criminal intent. Although the proportion of fires that are caused by electricity infrastructure is low—possibly about 1.5 per cent of all ignitions in normal circumstances—on days of extreme fire danger the percentage of fires linked to electrical assets rises dramatically. Thus, electricity-caused fires are most likely to occur when the risk of a fire getting out of control and having deadly consequences is greatest.

Altered ecosystems can also have a profound impact; the introduction of African gamba grass[318] to northern Australia has greatly intensified wildfires there. Growing to 4m in height and competing strongly with native grasses, it can multiply the fuel load eightfold. New Zealand's Curran, Perry and Wyse[319] point out: "Plantations of highly flammable exotic species, such as pines and eucalypts, probably helped to fuel the recent catastrophic fires in Portugal and in Chile. In arid regions, such as parts of the U.S. southwest, the introduction of exotic grasses has transformed shrublands, as fires increase in severity."

An increased frequency, intensity or longer season of wildfires in some parts of the planet does not necessarily incriminate climate change. It may simply be that the population increased and so too did the number of firebugs, that expanding populations took aging electrical networks with them, that a recent tree-change brought people into closer contact with the bush, that misguided environmentalists prevented controlled burning, that flammable exotics invaded the landscape, and perhaps other reasons also. Focusing on CO_2 to prevent wildfires may prove to be as misguided as was focusing on eggs to prevent heart attacks. It will be a real tragedy if that focus diverts attention from proven preventive measures:

- Adequate and properly maintained firebreaks, including green firebreaks;
- Preventing or limiting the spread of highly flammable exotics;
- Maintaining safe electrical networks, placing them underground in high-risk areas;
- Regular planned/controlled burning at appropriate times/weather conditions;
- Timely effective communication to the public of fire risk, planned burns and smoke pollution;
- Making dwellings as fire-resistant and smoke-proof (sealed) as possible;
- Using effective portable air cleaners to reduce indoor smoke pollution, especially for asthmatics.

Such measures, of course, are costly and unaffordable by countries deprived of cheap energy, those African and Asian countries most at risk from wildfires and smoke inhalation. Rather than increasing the global mortality from wildfires, the use of fossil fuels might actually be reducing it in more ways than one.

Food, Famine, Climate and CO_2

Fifty years ago, in his book The Population Bomb, Paul Ehrlich predicted widespread famine with hundreds of millions starving to death in the 1970s. Instead, the death toll from famines declined even as the population grew (Fig. 27).

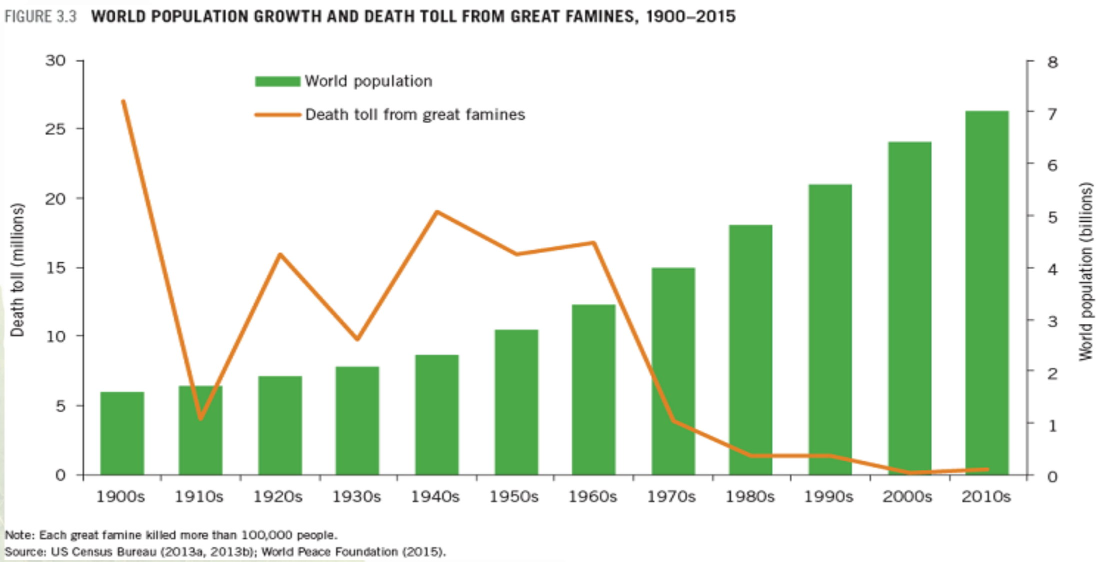
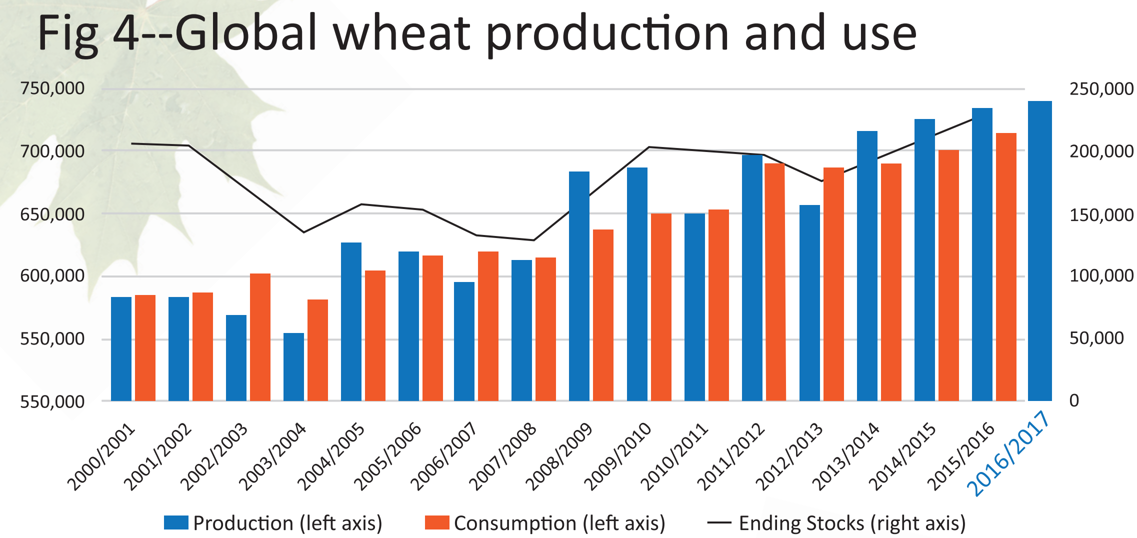


Figure 27: Global population (billions) and mortality from great famines (millions)

While Ehrlich was wringing his hands, an agronomist from Minnesota, the late Norman Borlaug rolled up his sleeves and quietly launched a green revolution in Mexico, Pakistan, India and elsewhere. Mexico became a net wheat exporter in 1963 and the Philippines became a rice exporter in 1968. By 1970, India and Pakistan had more than doubled their wheat production, and "the man who saved a billion lives" was awarded the Nobel Peace Prize for his work. Thanks to fossil fuels and Borlaug's disease-resistant high-yield hybrids and fertilisers, global food production increased by 2.3% pa from 1961 to 2005, which was faster than the 1.7% pa population increase. Food consumption increased from 2280 kcal/d to 2800 kcal/d per person, and a strong correlation was observed between agricultural growth rates and GDP; the only region where food production per capita has not increased is sub-Saharan Africa.[320] Africa's food production was predicted in 2008 to decline by as much as 50% by 2020 due to climate change.[321] The major threat, however, is not climate change but civil war and the armyworm, a native maize-munching moth of the Americas which turned up in Nigeria early in 2016 and spread rapidly across the continent. The American industry was saved by a bacterium gene which scientists inserted in Bt maize, making it toxic to the fall armyworm but not to humans. South Africa, the only African country to approve Bt maize, had a record crop in 2017.[322]

In 2013, the IPCC's AR5[323] stated: "For the major crops (wheat, rice, and maize) in tropical and temperate regions, climate change without adaptation is projected to negatively impact aggregate production for local temperature increases of 2°C or more above late-20th-century levels." In *Nature Climate Change*, Asseng *et al.* (2015) [324] warned: "warming is already slowing yield gains at a majority of wheat-growing locations. Global wheat production is estimated to fall by 6% for each °C of further temperature increase." This prompted a media report[325] that India "produced one million metric tons more wheat in 2013 than it did in 2014." But this was due to drought. After global temperatures climbed to record levels, *The Times of India* (17 August 2017)[326] reported a record food-grain production of 275.68 million tonnes, up

4% on the previous record, a five-fold increase since 1951 and a four-fold yield per hectare. The global wheat production reached record levels due to increases in India, Russia and the U.S. (Fig. 28). In March 2018, *The Guardian*[327] reported on durum varieties that can withstand constant 40°C temperatures.



Graph from Food Security Porta, with latest USDA figure estimated added. (joannenova.com.au)

Figure 28: Global wheat production this century (thousand tons pa). Source: World Grain, November 2016[328]

Global warming extended the arable area, growth rate and growing season for food crops.[329] From 1980 to 2003, global food production increased by 62.8% as atmospheric CO_2 increased by 11.2%, fertiliser use by 27.5% and land use barely at all.[330] Numerous studies of CO_2 enrichment in chambers (e.g. greenhouses) have demonstrated dramatically improved crop yields.[331, 332] Ainsworth-Long (2005)[333] performed a meta-analysis of 124 papers on 40 species tested at 12 sites, 7 in the USA, 3 in Europe, 2 in New Zealand and Japan, using free-air CO_2 enrichment (FACE). The actual increases achieved (above the ambient CO_2 level at the time of the study) varied from 30.5% to 68% with a median of 50-55% (550ppm) and an average of 49.2%. They found that trees benefited the most, more than anticipated from chamber studies, while average crop yields increased by 17%, less than expected from chamber studies. The overall trend level for wheat was about 15%. Sorghum yields increased by as much as 28% under dry conditions, due to reduced water loss from fewer transpiration stomata. Light-saturated CO_2 uptake was increased by 19% at temperatures under 25°C and by 30% at higher temperatures, indicating much better heat-tolerance under elevated CO_2. Elevated CO_2 also reduced the toxic effects of ozone. Two FACE facilities using CO_2 at up to 200ppm above ambient levels produced a 5-7% increase in rice yield and 8% increase in wheat yield, which would result in an extra 59 million metric tons a year globally, enough to feed an extra 550 million mouths at the average per capita consumption. Reducing atmospheric CO_2 to preindustrial levels, advocated by some climate activists, would put billions of lives at risk of starvation and thus constitute a crime against humanity. See our White Paper: ***The Climate Surprise – Why CO2 is Good for the Earth***.[334]

Moreover, CO_2 fertilisation has been shown to significantly increase the flavonoid content of wheat[335] and strawberries.[336] Wang *et al.* (2003) found that increasing the CO_2 concentration by 300ppm and 600ppm increased strawberry flavonoids by 55% and 112%, ascorbic acid (vitamin C) by 10% and 13% and glutathione (another antioxidant) by 3% and 171% respectively. Tomatoes grown in enriched CO_2 are higher in vitamins A[337] and C.[338] Idso *et al.* (2002)[339] found that CO_2-enriched oranges were 4% heavier, 74% more in number and 5% higher in vitamin C. Soy beans grown from seedlings in CO_2 at 700ppm (compared to 400ppm) had an isoflavone content 8% higher when grown at the usual mean temperature of 18ºC, 104% higher when grown at 23ºC and 101% higher at 28ºC.[340] When drought was added to heat stress, the isoflavone content was 38-186% higher in plants exposed to 700ppm. Kim *et al.* (2005) likewise found a 72% increase in soy isoflavones grown at 650ppm (vs. 360ppm), and a 96% increase in total plant biomass. Broccoli grown in 65%-enriched CO_2 produced heads 7% heavier and containing 37% more glucosinolates.[341] These enhance flavour and are thought to help prevent cancer.[342] Similar results were found with Chinese kale.[343] Growing spinach at 800ppm increased the fresh weight by 67%, the soluble protein concentration by about 52% and vitamin C by 21%.[344] Gwynn-Jones *et al.* (2012)[345] found that quercetin glycosides and various other antioxidants were significantly higher in several types of berry consumed by humans and other animals at Northern Latitudes when grown at 600ppm. It is very likely that CO_2 has been quietly improving food quantity and quality.

Global food security depends not only on production but also on distribution and transport, which invariably involves the use of fossil fuels. Famine and starvation in the developing world is usually the product of politics plus natural disaster, sometimes aggravated by climate change but more often by misguided climate action. The most notable example is the diversion of good food into biofuel. Goklany (2011)[346] estimated that such activities in 2008 helped to push 130-155 million people into absolute poverty, hunger and starvation, and may have led to 190,000 premature deaths in 2010 alone. Australia is a major wheat exporter, but a 2007 CSIRO report warned that "If all of the ethanol capacity that is currently proposed was to be fulfilled by existing crops (principally wheat and sugar), or if a national E10 target were to be met (eg. by 5.5 Mt of wheat as the feedstock), it could force the import of wheat in drought years." Despite a severe drought in 2012 in the U.S., 40% of its corn crop[347] went into ethanol. The real irony is that "Once estimates from the literature for process emissions and displacement effects including land-use change are considered, the conclusion is that U.S. biofuel use to date is associated with a net increase rather than a net decrease in CO2 emissions."[348] It is worse than useless! Such folly persists only because of politics and taxpayer subsidies to big business.

Seafood plays an important role in food security, supplying about 10% of world human calorific intake.[349] The omega-3 fatty acids (ω-3 FAs) produced by plankton at the bottom of the food chain probably reduce[350] cardiovascular morbidity and mortality and may benefit some metabolic, inflammatory, neurological, neuropsychiatric and eye disorders.[351] The UK Scientific Advisory Committee on Nutrition guidelines (2004) recommends at least two portions of fish a week. It is thought that increasing CO_2 will impact seafood via higher sea surface temperatures, ocean 'acidification' (actually slightly reduced alkalinity), altered precipitation/runoff and sea level rise. Crustaceans (crabs, lobsters, shrimps and krill) appear to benefit from more dissolved CO_2 even at seven times today's atmospheric level.[352] Relying on extreme emission/temperature scenarios, Cheung *et al*. (2009)[353] report:

> Here, we project changes in global catch potential for 1066 species of exploited marine fish and invertebrates from 2005 to 2055 under climate change scenarios. We show that climate change may lead to large-scale redistribution of global catch potential, with an average of 30–70% increase in high-latitude regions and a drop of up to 40% in the tropics. Moreover, maximum catch potential declines considerably in the southward margins of semienclosed seas while it increases in poleward tips of continental shelf margins. Such changes are most apparent in the Pacific Ocean. ... Many highly impacted regions, particularly those in the tropics, are socioeconomically vulnerable to these changes. Thus, our results indicate the need to develop adaptation policy that could minimize climate change impacts through fisheries.

Increasing atmospheric CO_2 is having uncertain positive and negative impacts on seafood supplies. One thing is certain: "global marine fisheries are underperforming economically because of overfishing, pollution and habitat degradation."[354] We need to focus on real problems, particularly plastic pollution of the oceans. For a comprehensive review, see *Ocean Acidification* by Patrick Moore in our White Paper: ***The Climate Surprise – Why CO2 is Good for the Earth***.[355]

Social Strife and Mental Health

Climate change is predicted to cause major social dislocations and mental health problems. In a forecast prepared for the Pentagon in 2003, Schwartz and Randall[356] predicted (among many others):

> In 2007, a particularly severe storm causes the ocean to break through levees in the Netherlands making a few key coastal cities such as The Hague unlivable [sic]. ... Melting along the Himalayan glaciers accelerates, causing some Tibetan people to relocate. . . .
>
> 2010: Border skirmishes and conflict in Bangladesh, India, and China, as mass migration occurs toward Burma
>
> 2012: Severe drought and cold push Scandinavian populations southward, push back from EU
>
> 2012: Flood of refugees to southeast U.S. and Mexico from Caribbean islands
>
> 2015: Conflict within the EU over food and water supply leads to skirmishes and strained diplomatic relations

Needless to say, none of these prophesies were fulfilled. Owain and Maslin (2018)[357] found "that climate variations played little or no part in the causation of conflict and displacement of people in East Africa over the last 50 years. Instead, we suggest rapid population growth, low or falling economic growth and political instability during the post-colonial transition were the more important controls." In his

2004 bestseller, *The Weather Makers*, Tim Flannery predicted:

> When we consider the fate of the planet as a whole, we must be under no illusions as to what is at stake . . . the fate of hundreds of thousands of species, and most probably billions of people. (p. 170) It seems inevitable that these [Pacific Island] nations will be destroyed by climate change during the course of this century. (p. 287)

Besides many more wild exaggerations, this book contained numerous contradictory statements and factual errors.[358] In 2006, Al Gore's docudrama, *An Inconvenient Truth*,[359] emotively depicted polar bears drowning, oceans rising 20 feet, dreadful epidemics and more – all happening very soon unless we 'save the planet'. After being shown in Australian schools, a 2007 survey of 600 children aged 10 to 14 revealed that 44% were nervous about the future impact of climate change and, "a quarter honestly believe the world will come to an end before they get older."[360] A subsequent survey of 200 schoolchildren in New South Wales likewise found that fears over climate change were producing feelings of powerlessness and despair: "Many children thought they would not survive to adulthood."[361] What does this do to career aspirations! Do predictions of perpetual drought cause farmers to abandon hope? The climate of fear campaign has produced more anxiety and despair than has climate change itself.

Climate change catastrophism has also polarised society. Merchants of fear attack Merchants of Doubt.[362] Sceptics of *catastrophic* climate change are suspected of big-oil funding but labelled paranoid if they suspect scientists of being biased by big-government funding. Robust scientific debate has been replaced by a claimed 97% scientific consensus,[363] where there is no consensus on ***how much*** anthropogenic warming has occurred or will occur,[364] especially when carefully analysed.[365]

Society is also becoming increasingly litigious over climate change: the Commonwealth Bank of Australia[366] and even financial advisors[367] for failing to disclose climate change risk in reports; the UK government[368] and ministers[369] for failure to fight climate change; the Dutch[370] and U.S. governments;[371] Californian cities and counties claiming damages from rising seas, storms and wildfires against oil companies[372] and receiving counter-claims.[373] As early as 2002, Tuvalu[374] threatened to take legal action against the worst emitters of greenhouse gases, the United States and Australia, because their island would soon be swallowed by rising seas and their 11,500 people would become the world's first climate refugees. Sea level around Tuvalu actually fell during the latter half of the 20th century.[375] For more information on sea level, see our White Paper: ***A Primer on Carbon Dioxide and Climate***.[376]

Energy Sources and Health

Existing energy sources include:

- Fossil Fuels – coal, oil and gas
- Biomass (wood, crop waste and dung) and Biofuel (ethanol and biodiesel)
- Wind and solar (photovoltaic and thermal solar)
- Hydropower including pumped hydro
- Nuclear power

Coal power has saved countless lives from drudgery, and taken many lives via the inhalation of soot. In a letter to the Financial Times (November 12, 2015), Lord Stern claimed that 7 million deaths each year were caused by the air pollution from fossil fuels, mainly coal. On 25 November, Bjorn Lomborg responded:

> The facts of the matter, as established by the World Health Organisation, are that the majority of air pollution deaths comes from indoor pollution, and about 85 per cent of these deaths are caused by biomass burning. This translates to 3.2m of the 7m deaths caused by indoor biomass burning. Moreover, a large part of the outdoor air pollution stems from non-fossil fuels. The most recent Global Burden of Disease estimates that 12 per cent of all outdoor air pollution comes from indoor air pollution, causing an extra 373,000 premature deaths. The most recent study from Nature estimates that just the indoor air pollution from households in China and India spilling into the open air causes 760,000 outdoor air pollution deaths. The Nature study shows that 600,000 outdoor air pollution deaths are caused by natural sources (mostly airborne desert dust). Another 660,000 deaths are caused by agriculture, mostly from release of ammonia, forming ammonium sulphate and nitrate. Finally, almost 200,000 additional deaths come from large biomass burning (forest burning such as we recently saw in Indonesia).
>
> Power generation, traffic and industry, which are mostly fossil fuel-driven and likely what Lord Stern was thinking about, in total cause 854,000 air pollution deaths. Added to the 560,000 deaths from indoor air pollution caused by coal, this constitutes only 20 per cent of total air pollution deaths, and hence is a far cry from Lord Stern's claim of a majority.
>
> This matters for two reasons. First, it is disingenuous to link the world's biggest environmental problem of air pollution to fossil fuels and indirectly climate. It is a question of poverty (most indoor air pollution) and technology (scrubbing pollution from smokestacks and catalytic converters) — not about global warming and CO2. Second, costs and benefits matter. Tackling indoor air pollution turns out to be very cheap and effective, whereas tackling outdoor air pollution is more expensive and less effective.

According to the World Health Organisation (WHO),[377] over 3 billion people still cook and heat their homes by burning biomass, and over 1.2 billion people have no access to electricity. Africa has 17% of the world's people but only 3% of its electricity.[378] By replacing biomass for cooking and heating, and supplying 39% of the world's electricity, coal prevents millions of deaths every year. By helping to lift people out of poverty, it saves millions more. High-efficiency low-emission (HELE) power plants[379] use scrubbers and precipitators to remove 99% of the fly ash, 97% of the sulphur dioxide and up to 90% of the nitrogen oxides. New ultra-clean coal (UCC) technologies can remove 99.75% of particulates and almost all the sulphur. Coal power in the U.S. is 17 times safer than in India and China (Table 1). India has huge coal reserves but mostly low-quality with high ash content,[380] so needs to import high-quality coal and/or build HELE plants.

There are hazards associated with the mining and transport of coal. Wikipedia lists 50 mining disasters[381] since 1885, mostly underground cave-ins and explosions. The worst year on record was

1907 when over 3,000 U.S. miners died.[382] Coal worker pneumoconiosis (CWP), commonly known as 'black lung', took about 25,000 lives globally in 2013.[383] After being eliminated in Queensland, Australia in the 1970s and in New South Wales a little later (Fig. 29), it recently re-emerged,[384] being confirmed in 18 Qld miners and one in NSW. The U.S. has been less successful in preventing CWP, probably due to the higher quartz content[385] in mine dust, especially in the central Appalachian region where one in ten miners are affected.[386] Modern open cut mining is much safer but not without accidental incidents. Particles less than 10 microns in diameter (PM10) pollute the environment. Spraying a bio-degradable binding polymer onto the surface has been shown to reduce coal dust lost to the environment by 75%. Queensland includes this in its extensive management controls.[387]

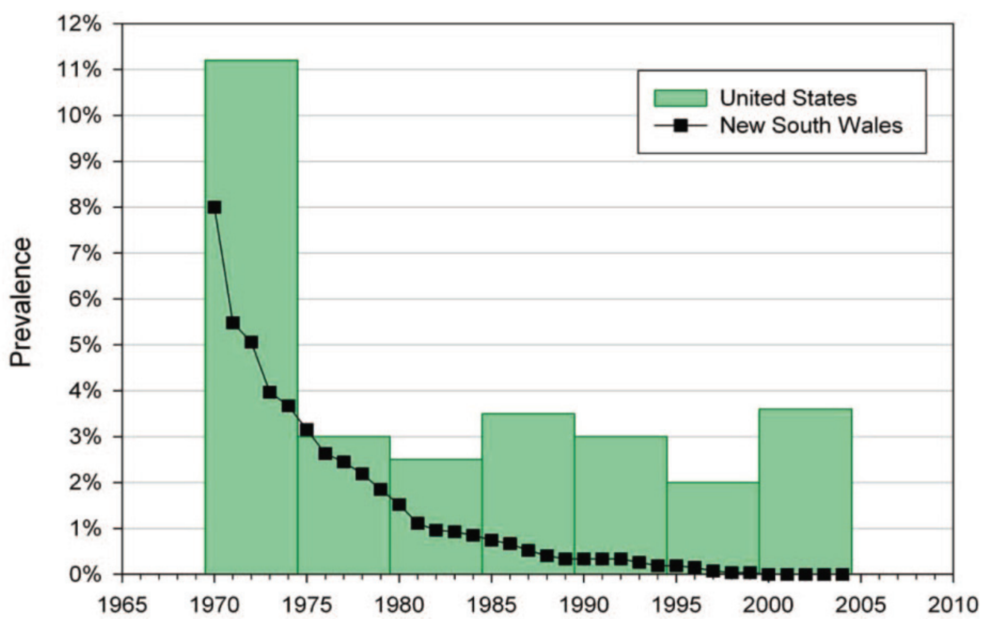


Figure 29: Prevalence of pneumoconiosis among U.S. underground coal miners and NSW coal workers.
Source: Joy, Colinet and Landen: CDC[388]

Oil and its distillates (petroleum, kerosene and diesel) revolutionised 20th century transport even more than did coal in the 19th century. Lead (added to petrol as anti-knock) contaminated the air and soil along busy roadways and smog plagued large cities until unleaded petrol and expensive three-way catalytic converters[389] were mandated in developed countries during the 1980s.

After Kyoto, the EU decided in 2001[390] to promote diesel to reduce CO_2 emissions. By 2016, most cars made for the European market were diesel. But diesel exhaust contains more nitrogen oxides and relatively high levels of particulates (soot) which catalytic converters can't remove. Diesel particulate filters (DPF) were mandated in the United States in 2007, but they tend to clog up during short trips around town, so periodic regeneration requiring more fuel is used to remove the accumulated carbon from the DPF. This led to computer tampering during testing. An honest study showed the latest "Euro 6 Standard" vehicles miss their pollution targets by a whopping 400%.[391] In a misguided attempt to reduce a non-pollutant (CO_2), Europe massively increased real pollution! After successive Indian governments subsidised diesel to assist farmers, the number of diesel cars increased ten-fold between 2000 and 2013. Delhi now has the world's worst air-pollution, killing up to 50,000 people a year according to the WHO.[392] Biodiesel is no less polluting. Cities could be made cleaner, cooler and quieter by replacing combustion engines with electric motors. While electric vehicles today are mostly coal-powered, they will eventually be mostly nuclear-powered.

Gas (methane), which produces almost no pollutants and less CO_2 per unit energy (Table 1), is fast replacing coal in the United States. Fracking[393] for shale gas has a good safety record and opposition is waning.[394] Being far more flammable than other fossil fuels, its storage and distribution requires stringent safety standards. The CBS News[395] reported: "In 2009, there were 158 natural-gas distribution pipeline incidents reported to PHMSA that killed 10 people, injured 50 and caused almost $32 million in property damage."

Table 1: Pounds of CO2 emitted per million British thermal units (Btu) of energy for various fuels.

Source: U.S. Energy Information Administration[396]

Fuel Source	**Lbs. CO_2**
Coal (anthracite)	228.6
Coal (lignite)	215.4
Coal (bituminous)	205.7
Diesel fuel and heating oil	161.3
Gasoline (without ethanol)	157.2
Propane	139.0
Natural gas	117.0

Biomass accounts for about 10% of global energy consumption[397] and around 90% in South Asia and sub-Saharan Africa (except South Africa).[398] It is unquestionably the most air-polluting and lethal of all energy sources. The WHO[399] states: "4.3 million people a year die prematurely from illness attributable to the household air pollution caused by the inefficient use of solid fuels (2012 data) for cooking. Among these deaths, 12% are due to pneumonia, 34% from stroke, 26% from ischaemic heart disease, 22% from chronic obstructive pulmonary disease (COPD), and 6% from lung cancer." The WHO[400] estimates that polluted air impacts 90% of people, kills around 7 million annually and accounts for 36% of lung cancer deaths, 34% of stroke deaths, 27% of heart disease deaths and 11.6% of all deaths globally. **Ambient (outdoor) air pollution** comes from dust, forest fires and burning biomass as well as from fossil fuels. Lelieveld *et al.* (2015)[401] attributed 90% of the ambient air pollution in South Asian megacities to the burning of biomass in homes. Mikko Paunio,[402] an epidemiologist at the University of Helsinki, recently stated:

> Thus perhaps around six million deaths globally are attributable to domestic combustion of solid (bio)fuels. However, despite these appalling statistics, the development community has focused its efforts on mitigating global warming instead. Some . . . have even encouraged the burning of crop residues in homes. The effect of this headlong rush to 'save the climate' has horrifying implications for human health.

Paunio also points out that burning wood pellets in Europe is not only more polluting than coal but also increasing CO_2 emissions.[403] The same applies to most biofuel, as discussed under food and famine.

A large prospective study from 2000 to 2009 across the United States indicated that fine particulate matter (≤2.5 microns or PM2.5) levels over 10μg/m^3 increased total mortality by 3%, CVD mortality by 10% and respiratory mortality in never smokers by 27%.[404] The most air-polluted region of the planet, with an annual mean ambient PM 2.5 of greater than 26μg/m^3, stretches band-like from northwest Africa across Arabia and northern India to eastern China; countries with the highest CO_2 emissions per capita, Australia, Canada and United States, have among the lowest actual air pollution (i.e. PM2.5 ≤10μg/m^3); only Siberia, Scandinavia, Scotland and Ireland have less, and the only areas in Australia with a PM2.5 greater than 10μg/m^3 are in the wildfire-affected north and the dry undeveloped centre.[405] The answer to life-threatening air pollution is development, and that requires the intelligent use of fossil fuels.

Solar power includes both photovoltaic (PV) and thermal solar plants, some of which can store heat for use after sundown. There are hazards associated with PV in the manufacture, rooftop installation, cleaning, servicing and removal/replacement.[406] Potentially toxic materials used in PV manufacture include silicon, gallium arsenide and cadmium,[407] cadmium telluride providing the best energy return on energy invested (EROI = 32:1).[408] The PV solar industry has also become one of the leading emitters[409] of hexafluoroethane, nitrogen trifluoride and sulphur hexafluoride, potent and potentially toxic greenhouse gases.[410]

In the U.S. construction industry, falls are the leading cause of fatalities, 269 from ladders and roofs in 2002. Brian Wang (2008)[411] estimated 100-150 fatal falls from solar panel roof installations annually. As PV solar is only about 15% efficient, most insolation on black solar panels is converted to heat, thus contributing to urban heat. Lasting less than 30 years[412] and containing lead, chromium and cadmium, they create 300 times more toxic waste per unit of energy produced than do nuclear power plants; a solar waste crisis looms.[413] PV solar panels also require the most resources per unit of energy produced (Fig. 30).

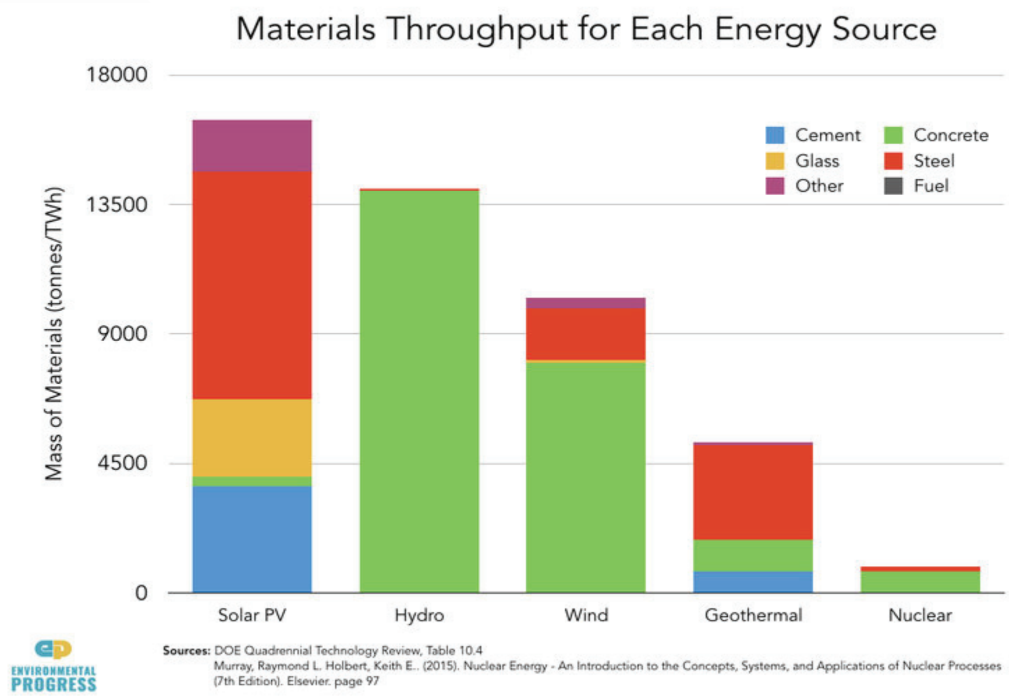


Figure 30: Material resources (tonnes) per unit energy produced (TWh). Source: Desai and Nelson (2017).[414]

Wind power impacts human health in the manufacture and installation of turbines, in the visual amenity, noise, economic and agricultural impacts; many European farms are growing turbines instead of turnips! Most fatalities associated with wind (Table 2) occur during the transportation and installation of turbines. With nacelles the size of buses and blades 50m long, reaching heights of 150m and sweeping an area of 1.9 acres with each rotation, wind turbines blight the landscape. Sunlight flickering through rotating blades can be annoying, and at 3Hz can trigger an epileptic seizure in susceptible subjects.[415] While one acclaimed U.S. study found that wind turbines had no impact on real estate values,[416] a UK study[417] showed wind turbine visibility reduced house prices substantially.[418]

Studies and reports on wind turbine noise are many, varied and often biased.[419] A comprehensive review by Schmidt and Klokker (2014)[420] found: “Wind turbines emit noise, including low-frequency noise, which decreases incrementally with increases in distance from the wind turbines. Likewise, evidence of a dose-response relationship between wind turbine noise linked to noise annoyance, sleep disturbance and possibly even psychological distress was present in the literature. Currently, there is no further existing statistically-significant evidence indicating any association between wind turbine noise exposure and tinnitus, hearing loss, vertigo or headache.” Infrasound (<20Hz) at 1000m from large wind turbines (>2MW) or 500m from smaller ones was very similar to that 8km inland from the coast (56-58dB), and less than that at 350m from a gas-fired power plant, 25m from the waterline at the beach or 70m from major roads (74-76dB). Rather than aggravating Meniere's disease, infrasound pulses at 6Hz can be therapeutic.[422] Infrasound in the 5–8 Hz range can nevertheless cause a rattling of doors and windows which is audible and can be annoying to those living in close proximity to wind turbines.[423] Schmidt and Klokker, noting the inability of cross-sectional studies to determine a clear causal relationship, state: "It is therefore not known with certainty if the association between wind turbine exposure and health-related outcomes is caused by sound exposure, visual disturbance, economic aspects or something else."

Tang *et al*. (2017)[424] found that wind turbines in northern China affected the soil temperature and moisture of nearby farms, thereby reducing gross summer production by 8.9% and annual net production by 4%. Decommissioning[425] of Europe's earliest offshore wind turbines, after about 25 years of operation, reveal an EROI of about 1:1 or less. The major problem with wind and solar is its intermittency and unreliability. Nearly half of South Australia's electricity came from wind turbines when strong wind forced their shut down in September 2016, resulting in a state-wide blackout.[426] South Australia has the highest electricity price and unemployment rate in Australia. California, Denmark and Germany likewise have the world's highest[427] use of renewables and electricity prices. Expensive power increases fuel poverty and cold-related mortality.

Hydropower is the most reliable renewable energy, provided the rain comes. MacLean *et al.* (April 2018) reported in The Washington Post: "Low water levels at these big dams, such as Ghana's Akosombo Dam,[428] built under the guidance of the country's first president, Kwame Nkrumah, cause frequent load shedding and blackouts. In November 2017, Tanzania experienced a nationwide blackout[429] and has faced recurrent blackouts for a decade because of low water levels from drought."[430] Pumped hydro allows surplus energy to be stored while the wind blows and the sun shines. It is vital that dams and reservoirs are well designed and built only on suitable sites. When the Banqiao dam on the Ru River in China burst in 1975, more than 170,000 people perished. A 1972 dam failure in Buffalo Creek, West Virginia took 125 lives, injured over 1,100 and left nearly 5,000 people homeless. In 1972, a dam near Rapid City, South Dakota, failed, which flooded the entire downtown during the night. This event killed 237 and injured 2,932 people.

Nuclear power has been on the nose since a tsunami hit Fukushima on 11 March 2011, even though no one died from radiation.[431, 432] Nuclear has by far the lowest fatality footprint, especially in responsible countries such as the U.S. (Table 2). Given that there have been only 50 confirmed deaths[433] from nuclear power plants, including Chernobyl, the estimate of 90 per PWh in Table 2, prepared by Conca,[434] who relied on Brian Wang (2008) and some questionable assumptions, is a gross exaggeration. According to Conca, wind and nuclear have the smallest carbon footprint (~15 g emitted per kWhr). Unlike early wind turbines, nuclear power has an EROI of 70:1[435] and requires far fewer resources (Fig. 30). Laser enrichment[436] of radioactive waste and fusion breeding[437] might soon revolutionise the nuclear industry, making it more efficient and safer than ever.

Table 2: Mortality rate per unit of power produced by energy sources (2012)

The numbers combine actual deaths and epidemiological estimates, and are rounded to two significant figures

Energy Source	Deaths/PetaWh	Percentage of energy type
Coal – global average	100,000	41% of global electricity
– China	170,000	75% of China's electricity
– U.S.	10,000	32% of U.S. electricity
Oil	36,000	33% of global energy – 8% of electricity
Natural Gas	4,000	22% of global electricity
Biofuel and Biomass[#]	24,000	21% of global energy
Solar - rooftop	440	<1% of global energy
Wind	150	3% of global electricity
Hydro – global	1,400	16% of global electricity
– U.S.	5	6% of U.S. electricity
Nuclear – global	90	17% of global electricity
– U.S.	0.1	19% of U.S. electricity

[#]Biofuel greatly dilutes the Biomass fatality rate. Source: James Conca in Forbes[i]

For optimal health, every country should be free to choose the most affordable and reliable energy sources. Those using coal should be encouraged and perhaps assisted to make it as clean as possible. Most will probably transition to gas and eventually to nuclear energy. Biomass should be phased out, as should all subsidies, and intermittent renewables must remain minor players. The underlying principle should be the conservation and best use of resources.

Conclusion

Warmth is good for human health and prosperity. Fossil fuels have played a vital role in providing the wealth essential for health and environmental protection. They have also boosted atmospheric CO_2 and added a little warmth, both being hitherto beneficial overall for plants and people. The ingenuity of Homo sapiens at adapting to climate has permitted people to populate almost the entire globe. No other animal has managed to thrive in the freezing Arctic and steamy tropics. If we stick to doing what we do best – adaptation – we will not only survive global warming, we will continue to thrive. We must be prepared not only for global warming, but also for global cooling, which will occur as our present warm Holocene draws to its inevitable end.

Human health and that of the planet depends on balancing productivity and development with conservation and environmental protection. Only developed countries with people lifted out of poverty can afford to produce clean energy, protect the environment, put power underground, construct buildings with 5-star energy ratings and use efficient lighting/appliances to minimise energy and water use, provide adequate safe water supplies and effective public health measures to control communicable diseases. It is vital that governments focus on real pollutants, not imagined ones, and that they avoid using climate change as a scapegoat for failure to implement sound public health policies and proven preventive measures. Misguided climate action can be worse than unmitigated climate change. When women (in particular) are educated and agriculture is mechanised, as in the developed world, fertility rates drop and population growth slows, thus reducing social and environmental pressures, conflict and emigration.

Urban design can be improved to reduce urban heat, and to encourage health-promoting walking and cycling. Smoggy cities could also encourage a switch to electric vehicles, but not with generous taxpayer-funded subsidies. Energy costs need to be kept as low as possible, especially in cold climates, so that poor people can afford to keep warm in winter. For every death from heat, there are twenty from cold. Fossil fuels, including clean-coal will continue to have an important role to play in advancing civilisation and human health over the 21st century. Our focus should be on conservation and health-promoting activities rather than on CO_2 and climate change. Unmitigated warming this century is likely to be less than 1°C and thus more beneficial than harmful for humanity and perhaps for the planet.

We concur with the latest IPCC Summary for Policymakers:[438] "The most effective vulnerability reduction measures for health in the near term are programs that implement and improve basic public health measures such as provision of clean water and sanitation, secure essential health care including vaccination and child health services, increase capacity for disaster preparedness and response, and alleviate poverty (very high confidence)."

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The mission of the CO2 Coalition is to promote broader understanding of the beneficial effects of more carbon dioxide in the atmosphere around the world. The Coalition fosters informed debate on the scientific evidence, as summarized in this Primer. The Coalition's initial paper, published in the fall of 2015, urged the public to "see for yourself."

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