Cancer and climate change

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The acute impact of climate change on human health is receiving increased attention, but little is known or appreciated about the effect of climate change on chronic diseases, particularly cancer. This Review provides a synopsis of what is known about climate change and the exposures it generates relevant to cancer. In the context of the world's cancer burden and the probable direction we could expect to follow in the absence of climate change, this scoping review of the literature summarises the effects that climate change is having on major cancers, from environmental exposures to ultraviolet radiation, air pollution, disruptions in the food and water supply, environmental toxicants, and infectious agents. Finally, we explore the effect of climate change on the possible disruption of health systems that have been essential to cancer control practice. We conclude with potential responses and opportunities for intervention.

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Introduction

The reality of climate change and its impact on human health are no longer in the realm of speculation.[1] International scientific organisations, such as the Intergovernmental Panel on Climate Change, have long predicted the disruptions in planetary ecology and human health that the world now faces.[2]

Health researchers and physicians have long known about the effects of climate change on infectious diseases and the conditions caused or exacerbated by limited access to safe and nutritional food and water.[3] However, the effects on chronic diseases such as cancer are less clear than the effects on infectious diseases because chronic diseases do not occur in close temporal proximity to the exposures brought about by climate change. This Review provides a synopsis of what is known about climate change and the trends in the world's cancer burden. We then review the literature on the effects of climate change on major cancers and on the health systems that have been essential to successes in cancer control.

Climate change now

The 5 years from 2015 to 2019 were the warmest 5 years on record.[4] Human activities, principally the burning of fossil fuels, have caused global average temperatures to rise by around 1°C above pre-industrial levels.[2] This warming has caused a range of associated climatic changes, including loss of glaciers and polar ice sheets, rise of sea levels, warming of oceans and ocean acidification, unpredictable changes in rainfall, increased intensity of storms and floods, increased frequency of extreme weather events, and increased frequency and severity of heatwaves, droughts, and wildfires.[3] These environmental changes have tremendous impacts on human health and global development.[2] Tragically, the effects of climate change disproportionally affect already disadvantaged low-income communities and countries that are the least responsible for the causes of climate change.

The impacts of climate change on health are widespread, diverse, and growing rapidly. High temperatures, poor air quality, and wildfires cause rising rates of respiratory and cardiovascular diseases. Rising temperatures and changing rainfall patterns increase the risk and spread of vector-borne diseases, such as dengue. The collapse of fisheries and declining agricultural production threaten the global food supply. Water scarcity, drought, and poor water quality increase the risk of water-borne diseases. Extreme weather events cause death, injury, and displacement, and disrupt health-care delivery.[1,5,6]

The Paris Agreement on climate change established a global target of limiting the temperature rise to less than 2°C above pre-industrial levels, with efforts to keep warming below 1·5°C. These thresholds are widely considered the limits beyond which severe impacts on human and environmental health will occur. Without ambitious climate action, global temperatures are expected to rise by 3°C or more above pre-industrial levels by 2100.[2,7] For these reasons, taking action on climate change has been called "the greatest global health opportunity of the 21st century".[5] Yet environmental pollution continues to rise, along with the risk of growing health impacts.

Cancer burden now

Global trends indicate that cancer is likely to become the leading cause of death and principal barrier to increased life expectancy in the 21st century for virtually every country in the world.[8] According to analysis from the Global Burden of Disease Study, there were 16·8 million new cases of cancer and 9·6 million deaths in 2017.[8] This is a striking increase from 2008, when there were 12·7 million incident cancer cases and 7·6 million deaths.[9] The International Agency for Research on Cancer (IARC) GLOBOCAN 2018 statistics align with these estimates.[10] A small number of cancer sites account for more than half of cancer deaths. In women, the most common incident cancers are breast, lung, colorectal, cervix, and stomach cancers and, in men, the most common are lung, liver, stomach, colorectal, and prostate cancers.[10] But, there is considerable heterogeneity in the type of cancers that are most common across countries and regions of the world, due to differences in genetic susceptibility, average lifespans, and social determinants of cancer, including the economic development of a country, levels of education, human behaviours, and the strength of health-care systems.[11]

What could be expected if the threat of climate change were not looming over us? If the experience of some

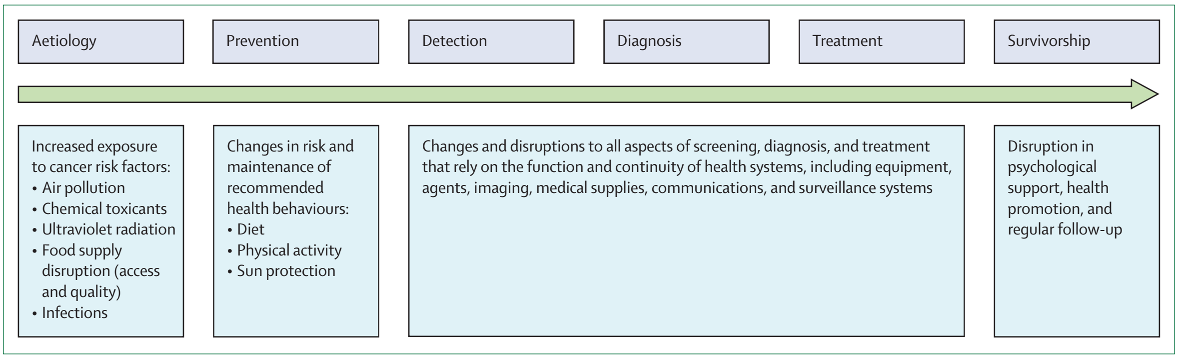

***Figure 1:* Climate change impact across the cancer control continuum**
Climate change is likely to affect cancer control actions all along the cancer control continuum from increasing causal factors and modifying behaviours for prevention and early detection, to disrupting health system factors that underlie early detection, diagnosis, treatment, and survivorship practices.

developed countries is taken as an example of where cancer control could go, the future looks optimistic.[12] Incidence and mortality rates for some major cancers and cancer overall are decreasing in high-income countries (HICs), such as Australia, New Zealand, the UK, and the USA,[13–15] largely because of progress in tobacco control, improved early detection, and better treatments. However, these trends are not shared by low-income and middle-income countries (LMICs), where cancer incidence is associated with increased smoking rates, excess bodyweight, and physical inactivity.[13] Nevertheless, it would be reasonable to expect improvements in LMICs over time as well, given what is understood about the underlying reasons for improvements in HICs, such as cancer control measures against known behavioural risk factors, effective programmes for early detection, improved treatments, and societal policy changes. The main environmental and social causes of cancer are amenable to interventions all along the cancer control continuum (figure 1), including actions against the use of tobacco products, unprotected exposure to ultraviolet radiation, some infectious agents, such as the human papillomavirus (HPV), toxic environmental chemicals, and dietary modification.[13] The current differences between HICs and LMICs can be used as a snapshot of a dynamic process whereby global improvements in cancer control and reductions in inequities would be expected given present day trends and appropriate resources. However, the consequences of climate change are likely to slow progress in cancer control, as described below.

The effects of climate change on cancer

The principal mechanisms through which climate change is likely to affect cancer control are through causal pathways involving air pollution, exposure to ultraviolet radiation, disruptions in food and water supply, exposure to industrial toxicants, and possibly infectious causes of cancer (figure 2). These effects are associated primarily with cancers of the lung and upper respiratory tract, skin, gastrointestinal tract, and liver. However, beyond these causal factors, we can expect major disruptions in the infrastructure of health-care systems for cancer control that could affect all cancers.

Observations on the potential effect of climate change on human health, including cancer, date back to the early 1990s with predictions from Sir Richard Doll[16] and others[17–19] of the adverse effects of the accumulation of greenhouse gases and the associated increasing global temperatures. However, most of the literature on the health effects of climate change has come within the past 10–15 years and is steadily increasing in volume.

Air pollution and lung cancer

Lung cancer is the primary cause of cancer mortality worldwide, and tracheal, bronchus, and lung cancers together accounted for 2·2 million incident cases and 1·9 million deaths in 2017.[8] Tobacco consumption remains the number one cause of lung cancer mortality but, as success has been achieved in tobacco control, air pollution poses an increasing threat. The severity of air pollution is increasing as a result of human activity and is itself contributing to climate change.[20,21] The *Lancet* Commission on pollution and health established that all forms of pollution cause 43% of lung-cancer deaths.[22] Particulate air pollution causes as many as 15% of all lung cancer deaths and deaths attributable to particulate pollution have increased by 20% in the past three decades.[23]

Multiple comprehensive cohort studies document the relationship between the major components of air pollution and lung cancer,[24] and IARC recognised air pollution as a carcinogen in 2013.[25] The carcinogenic elements that comprise air pollution include nitrogen dioxide, sulphur dioxide, ozone, particulate matter with a diameter of 10 micrometres or less (PM_{10}), and $PM_{2·5}$,[26] although $PM_{2·5}$ and ozone[27] are recognised as the most useful indicators for monitoring air pollution. Polyaromatic hydrocarbons, also designated as carcinogens by IARC,[28] are bound to $PM_{2·5}$, allowing them to reach deep into the lung.[20,29,30] Multiple studies have measured these pollutants under different circumstances[31–34] and one has modelled the effect of particulate air pollution over the 21st century worldwide and shown an increase in premature mortality

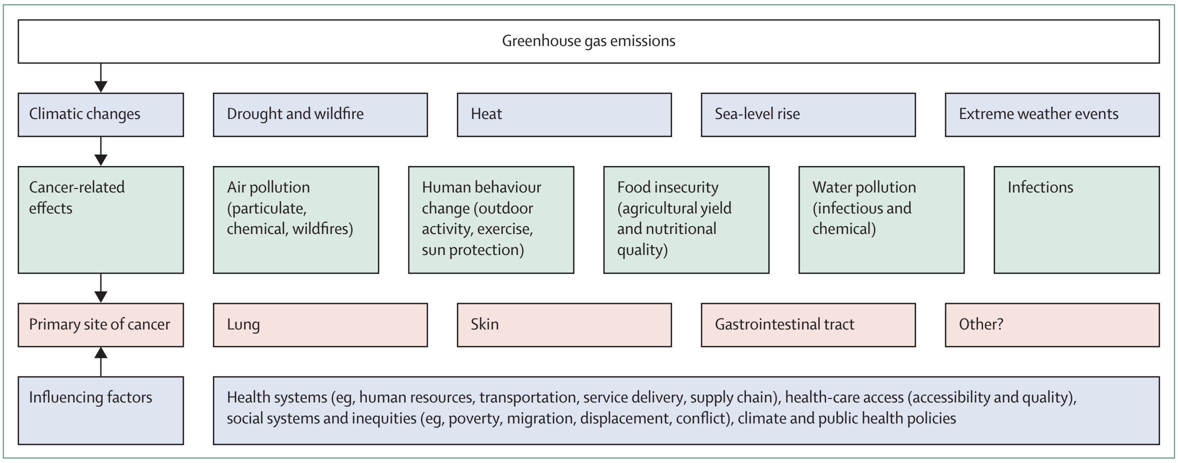

Figure 2: **Pathways from climate change to cancer outcomes**
Greenhouse gas emissions are resulting in climatic changes, such as rising temperatures, droughts, flooding, extreme weather events, and sea-level rise. In turn, these changes have cancer-related effects on air pollution, ultraviolet radiation exposure, food insecurity, water pollution, and infections, and will affect human behaviours, such as physical activity. The primary cancer targets are likely to be the lung and skin, and more general effects of climate change are likely to be related to poor nutrition and contaminated food and water supplies. Underlying these effects will be the disruption in health systems on which successful cancer control depends.

and lung cancer in all regions except Africa.[35] In a meta-analysis of a large number of cohort studies over the past 25 years, the estimated hazard ratio, adjusted for age, sex, and smoking status, was 1·13 (95% CI 1·07–1·20) per 10 μg/m³ elevation in $PM_{2·5}$.[24] Fewer studies exist on the effects of ozone than on the effects of $PM_{2·5}$, although evidence from one review found no association with lung cancer.[36]

Climate change will also increase particulate pollution through increasing the risk of wildfires and anticyclonic conditions (inversions) that increase concentrations of pollution and smoke. Wildfire risk is increasing because of drought, rising temperatures, and changes in precipitation, along with other human-driven factors such as land management and development patterns. Wildfire smoke generates $PM_{2·5}$ that contains polyaromatic hydrocarbons, benzene, and formaldehyde, which are known to be carcinogenic.[23]

Other cancers beyond lung cancer might also be affected by air pollution, although the evidence is less convincing than that for lung cancer. Evidence exists for an effect of exposure to environmental chemicals, such as polyaromatic hydrocarbons[37] and nitrogen oxides (NOx),[38] from air pollution and industrial products on early life development and breast cancer risk. One study from China found regional and international associations between concentrations of $PM_{2·5}$, other air pollutants, and gastric cancer.[39]

Air pollution-related lung cancer will ultimately decline over time if reductions in emissions can be achieved. A growing body of literature models the health co-benefits of mitigating policies, such as those that reduce air pollution. For instance, studies in China show substantial reductions in mortality, including from lung cancer, that would result from full implementation of China's climate policies.[40]

Ultraviolet radiation and skin cancers

An extensive amount of literature exists on the link between the increased exposure to ultraviolet radiation and the increase in squamous cell and basal cell cancers (now more commonly referred to as keratinocyte cancers) and melanomas.[41,42] The Global Burden of Disease Study estimates there were 7·7 million incident cases of keratinocyte cancer worldwide, with 65 000 deaths and a 33% increase in cases since 2007.[8] This increase is associated with ageing of the population, but exposure to ultraviolet radiation over extended lifetimes is the underlying mechanism. Ultraviolet radiation increases skin cancers directly through induction of gene mutations and indirectly through immunosuppression.[43,44] Melanoma rates worldwide have also increased steadily in recent decades and accounted for more than 230 000 incident cases and 55 000 deaths in 2012.[8] 76% of new melanoma cases could be attributed to ultraviolet radiation, primarily in North America, Europe, and Oceania.[8,45]

Ozone depletion, resulting from the use of aerosols, such as chlorofluorocarbons and hydrochlorofluorocarbons, has contributed to increasing ultraviolet light exposure and skin cancer.[46,47] However, the 1987 Montreal Protocol and its amendments have largely succeeded in reducing ozone layer depletion and, consequently, the likelihood of predicted increases in skin cancer by as much as 2 million cases by 2030.[48,49] An emerging body of literature exists on the potential direct effect of increased temperatures on skin cancer; however, evidence in humans is inconsistent and the relationship remains unclear.[50–52]

Human attitudes towards sunbathing have long been a concern for ultraviolet radiation exposure and skin cancer.[53] Rising temperatures associated with climate change result in behavioural changes, such as increasing time outdoors and shedding of protective clothing, that result in more ultraviolet radiation exposure[41] and skin cancers than with lower temperatures.[54] However, when temperatures are very high, people spend less time outside than they do with small increases in temperature, reducing exposure to ultraviolet radiation. So, although social behaviours are hard to predict, the effects of human behaviour in response to temperature increases will be a more important factor for skin cancer rates than the increase in ultraviolet radiation itself.[41,55]

The effect of greenhouse gases on the ozone layer and the attendant exposure to ultraviolet radiation have been heterogeneous across the globe.[42,56–59] Regions closer to the equator have higher ambient ultraviolet radiation, which can be exacerbated at high altitudes.[60] In Australia, where skin cancers account for more than 80% of all cancers, the Montreal Protocols have led to a decrease in the production of ozone-depleting substances. However, before recovery, increased levels of ultraviolet radiation are expected, associated with increased risk of skin cancers from human behaviours.[57]

Increasing malignant melanoma incidence has been tracked in European and North American cancer registries and linked to census and other individual-level data. One study in the white population of Canada, based on census data and geospatial methods, associated summertime exposure to ambient ultraviolet radiation with increased melanoma rates, controlling for age, sex, and socioeconomic variables.[42] However, this ecological study was not able to characterise exposures at the individual level nor capture variations in exposures over time.

Increased levels of vitamin D resulting from exposure to ultraviolet radiation have some salutary protective effects on cancer development.[53] Vitamin D, produced by the skin upon exposure to ultraviolet B radiation, has several positive health effects on musculoskeletal health, calcium metabolism, and immune function, but the balance between DNA damage and skin cancer from ultraviolet radiation and the beneficial effects of vitamin D remains a topic of investigation and diverging opinion.[53]

Nutrition, food supply, and cancer

The extensive studies of diet and cancer have uncovered many false leads, and intervention trials based on the best observational data have been frustratingly negative in terms of effectiveness. However, there is good evidence that healthy diets with whole grains, fruits, and vegetables are protective, at least for colorectal and breast cancer, and the highest risks for cancer are associated with the adverse effect of adult obesity and excessive alcohol consumption.[61]

Climate change is affecting the quality and quantity of food production in multiple ways. Rising temperatures, flooding, drought, extreme events (eg, hurricanes, typhoons), higher ground-level ozone, declines in pollinators (eg, honey bees), and sea-level rise all negatively affect food production and crop yields. Higher concentrations of ambient carbon dioxide also reduce the nutritional content of staple grain crops, including the amounts of protein and micronutrients.[62,63] Rising ocean temperatures and ocean acidification might reduce the productivity of fisheries. In some communities, this reduction could affect consumption of fish, and by extension omega-3 fatty acids that are protective against some cancers.[63] Rising sea levels are already affecting food production in some Pacific islands.[64] Studies suggest climate change also increases the production of mycotoxins, such as aflatoxins, which are of aetiological importance for liver cancer, although no evidence of increases in hepatocellular cancers associated with climate change have been directly attributable to aflatoxins.[65–67]

Although the overall effects of climate change on nutrition-related cancers are difficult to ascertain, a comprehensive modelling study predicted there would be 534 000 climate-related deaths worldwide, including deaths from cancer, as a result of changes in food supply by 2050, such as reduced consumption of fruits and vegetables.[62] This increase in mortality is not offset by a reduction in red meat consumption—brought about either by scarcity or mitigation efforts—that could save 29 000 lives by 2050.[62] Further, the reduction in colorectal cancer incidence associated with less red meat consumption is likely to be confined to HICs,[68] whereas for populations in LMICs with widespread undernutrition and malnutrition, a reduction in protein sources could have a detrimental effect on health.

Environmental chemicals

Environmental toxicants are likely to increase with increased industrialisation and chemical production independent of climate change. Coal-fired power plants, oil and gas extraction, and fracking are all linked to pollution in air and water, but climate change could further increase exposure to these environmental toxins. Modelling studies of chemical pollutants in glacial meltwater in the Alaskan Arctic and the Swiss Alps show elevated concentrations of persistent organic pollutants that can accumulate in the local fish supply and might increase lifetime cancer risk among populations with high degrees of local fish consumption.[69,70] Modelling studies suggest that public water systems increasingly face higher bromide concentrations in source waters from extraction industry activities, which could increase the lifetime bladder cancer risk in populations served by sampled water treatment plants.[71] Wildfires might also increase exposure to toxic chemicals through air pollution and through contamination of ground water. In California, USA, drinking and ground-water sources were contaminated with benzene following wildfires in 2018.[72] In addition, flooding might increase the risk of exposure to toxic chemicals; in the USA, over 2500 sites handling toxic chemicals are located in flood-prone areas.[73]

Infectious causes of cancer

Climate change is linked to increased risk of *Vibrio cholerae* infections and vector-borne diseases such as dengue and malaria,[3] but links to the infectious causes of cancer are not well documented. The prevalences of hepatitis B and C,[8] HPV, Epstein-Barr virus, and HIV, which play causative roles in cancer, are not directly related to climate change, although one study in Lesotho suggested that the response to drought included alterations in human behaviours independently associated with HIV risk through commercial and transactional sex.[74] In addition, there has been some speculation on the effect of climate change on other infections, such as *Helicobacter pylori* and its role in gastric cancer,[75] *Clonorchis sinensis* in cholangiocarcinoma, and *Schistosoma haematobium* in bladder cancer. However, the evidence remains sparse, with some reviews predicting that climate change is more likely to shift the geographical range of these infections rather than expand global risk.[76]

Health system effects

The most profound challenge to global cancer burden could come from the disruption of the complex and integrated health-care delivery systems required for cancer diagnosis, treatment, and care.[12] Extreme weather events such as storms and flooding can destroy or damage health-care infrastructure, reducing health-care quality and availability. These events also interrupt service delivery by causing power shortages, disrupting supply chains, transportation, and communication, and resulting in staff shortages.[77] For example, HPV infection is unlikely to be directly influenced by climate change, but screening, early detection, and vaccination could easily be disrupted, especially in LMICs where cervical cancer is most prevalent. Long-term disruptions in power and medical supply chains that result from extreme weather events are a particular threat for patients with chronic medical conditions or who require continuous care for treatment and management of their conditions. Radiation oncology services, for instance, are typically unable to operate on backup generators;[78] therefore, power outages resulting from extreme events or planned disruptions to the power supply, such as that to avert wildfire risk in California, can disrupt or delay cancer care. Extreme events also result in the loss of medical records, which in turn affects follow-up care for patients with cancer requiring highly individualised and complex care and treatment.[78] Interruptions in cancer treatment and disruptions to clinical trials[79] are associated with poorer treatment and survival outcomes.

Climate events might also reduce access to health-care services, including routine cancer screening, if road and transportation networks are affected. Increased temperature even affects the function and reliability of some screening immunological tests.[80] Disasters will probably overwhelm health system capacity as a result of surges in injuries, infections, and communicable diseases, and have implications for cancer care as resources are reallocated to disaster response.

Major disruptions to hospital functioning and capacity occurred following Hurricane Maria in Puerto Rico,[81] Hurricane Dorian in the Bahamas, Hurricane Sandy in New York, USA,[27,82] and Cyclone Idai in Mozambique,[83] among other climate-related disasters. After Hurricane Katrina in New Orleans, USA, there were substantial delays in oncology treatment due to damaged hospital infrastructure and radiotherapy equipment, and closure of health facilities and cancer treatment units.[78] Reduced access to cancer care and treatment services lasted for years after Hurricane Katrina, with substantial effects on the health of patients with cancer. 10-year breast cancer survival was lower for people exposed to Hurricane Katrina than for those who were not exposed.[84]

Sparse evidence on the impact of climate change and extreme events on cancer progression and survival suggests a negative effect. A systematic review of natural disasters and cancer found evidence of higher cancer mortality after disasters than before.[78] In addition, a systematic review of the effect of storms and flooding on non-communicable diseases including cancer found that these weather events increase the risk of disease progression and death.[85] In the USA, researchers found an association between hurricane disasters declared during radiotherapy and overall survival of patients with locally advanced non-small-cell lung cancer.[86]

Social determinants of cancer

Climate change is exacerbating existing social and economic inequities, within and between countries, and is leading to rising rates of migration, poverty, and conflict, which place people and communities at higher risk than normal for a range of health outcomes. Climate change and changing agricultural productivity can also negatively affect food distribution, increase food prices, and change food markets, contributing to malnutrition and food insecurity. Low-income communities and communities of colour are disproportionately affected by cancer and have a higher cancer mortality than the rest of the population.[11] The World Bank estimates that climate change will push 100 million people globally back into poverty by 2030.[87] This estimate is on top of other estimates that, by 2050, there will be over 140 million internal climate migrants in the regions of sub-Saharan Africa, south Asia, and Latin America alone.[88] Refugees and displaced people often have little access to health-care services in both their home and host countries, and are often diagnosed with more advanced-stage cancer than most people when they do present for care.[89] Research and action to address cancer and climate change must include analyses of the adverse effects of climate change on the social determinants of cancer.

Potential responses and opportunities for intervention

Although the effect of climate change on cancer remains largely unquantified, our Review indicates several pathways through which climate change increases cancer risk, incidence, and mortality. However, various clinical, behavioural, and policy solutions can limit climate change and minimise any potential excess cancer cases that might occur as a result.

Addressing climate change

Substantial opportunities exist for policies within energy, agriculture, transportation, health care, and other sectors to substantially reduce greenhouse gas emissions, slow climate change, and avoid extreme temperature and sea-level rise, and other climate changes and their attendant health effects.[12] Such climate change mitigation policies will also have near-term health benefits beyond cancer risk reduction. Perhaps most importantly, many climate policies will result in immediate reductions in air pollution. Meeting the Paris Agreement goals is estimated to save 1 million lives every year by 2050 as a result of declining air pollution, including reductions in cancer mortality.[90] Policies to increase use of active and public transportation, reduce vehicle emissions, and build sustainable agricultural systems can reduce air pollution, increase physical activity, and improve diets and food security.[91]

Mitigating exposure to climate-related cancer risk factors

Although climate change might increase exposure to cancer risk factors, population health interventions can offset potential increases in cancer risk through individual and community-wide behavioural and educational interventions. For example, individual behaviours such as minimising sun exposure and using sunscreen can modulate the relationship between climate change and skin cancer. Community interventions such as the establishment of clean-air shelters can reduce exposure to air pollution during wildfire events. Established cancer prevention and early detection activities along with effective health education and promotion efforts, if implemented proactively and widely, can reduce the increased cancer risk that might result from climate change.

Strengthening health systems and ensuring accessible, high-quality cancer care

Preparing climate-resilient health systems, ensuring continuity of care during climate events, responding effectively to changes in disease burden, and providing equitable access to high-quality care are essential to protecting human health. In addition, actions by health professionals to influence the social determinants of global inequities through policy changes and political leadership are needed to address the social determinants of cancer amplified by climate change.[12]

Limitations and future research

It is worth noting that the topic of cancer and climate change is extremely difficult to study because of the complex interplay of exposures and outcomes over time, multiple confounding factors, and the challenges of establishing causal relationships.[92] In addition, the attribution of either increases or decreases in cancer incidence to mitigation efforts is challenging given background trends and because the potential salutary effects of mitigation efforts will take years to realise. Thus, the quality of the literature reviewed is limited by the kinds of study designs and approaches that are possible with such complexity. There are no randomised controlled trials, few controlled studies, and a minimum of well-conducted observational population studies. Furthermore, cancer, unlike infectious diseases, has a long latency or incubation period between exposures and clinical diagnosis, as long as 10–20 years for most solid tumours. Studies that do not take this time lag into account make a questionable contribution to our understanding of the effects of climate change,[93] and the effects of mitigation efforts today might not be realised for decades by existing surveillance systems. Finally, it might well be that the most lasting and profound effects of climate change are through exposures that occur early in life and only manifest themselves decades later. Some of these effects could be on the biological mechanistic level, such as temperature effects on the human epigenome, and more studies on these mechanisms are needed than have been done so far.[94]

Conclusion

In the shared worldwide battle to mitigate climate change, the international community is not on track to slow emissions of greenhouse gases. Climate change and trends in air pollution, ultraviolet radiation exposures, food production and nutrition, environmental toxicants, and perhaps the effects on infectious causes of cancer are therefore likely to continue and worsen. Even so, it might take decades to study and fully understand the impact of climate change on cancer. Known causes of cancer are becoming more prevalent in many low-income countries and are likely to challenge our ability to maintain and achieve global progress in cancer control. Notwithstanding, mitigation efforts are having some success in reducing air pollution in some parts of the world.

At the time of writing, the world is engaged in efforts to combat a pandemic of COVID-19 that has sickened millions and killed hundreds of thousands of people across the globe. One consequence of the pandemic has been the shifting of medical resources away from cancer screening and timely treatment as the focus turns to caring for victims of the infection. The early pandemic response resulted in a striking reduction in air pollution, showing the potential of extreme measures to result in rapid environmental change. However, emissions have since rebounded nearly to prepandemic levels. Nonetheless, it

Search strategy and selection criteria

We did a scoping review of the literature for evidence of mechanisms, outcomes, and associations between cancer and climate change. We searched PubMed and Google Scholar (Feb 14, 2020) using the terms "cancer and climate change", "cancer and global warming", AND "cancer and greenhouse gases". We identified 608 unique articles in English and reviewed the titles and abstracts of these papers to identify 77 articles that mentioned some aspect of cancer and climate change. We then reviewed those articles according to a protocol that recorded study information, including the specific cancer and environmental determinants under study, and study methodology (eg, design, exposure measurement, outcome assessment). All articles that presented evidence of climate change on cancer or a cancer precursor were reviewed. 20 articles mentioned "climate change" or "cancer" only casually and were excluded. However, we included 11 commentaries or editorials that offered useful perspectives on cancer and climate change. Most of the selected 57 articles summarised existing knowledge with new insights or were modelling studies that estimated the effects on exposures in the future. We supplemented this Review with additional literature that explored the specific pathways from climate change to cancer.

might well be that the lessons from the present pandemic can be applied to the global challenge of climate change, including the need for investments in public health and health-care infrastructure, research, and intense collective action on health problems of a global scale.

Contributors

RAH conceived the organisation of the Review, did the literature search, and was the primary author. RAH and NB reviewed the literature and wrote and reviewed major sections of the Review. NB was primarily responsible for climate change science and RAH for cancer control science.

Declaration of interests

We declare no competing interests.

References

1 Haines A, Ebi K. The imperative for climate action to protect health. *N Engl J Med* 2019; **380:** 263–73.

2 Hoegh-Guldberg O, Jacob D, Taylor M, et al. 2018: impacts of 1.5°C of global warming on natural and human systems. In: Masson-Delmotte V, Zhai P, Pörtner HO, et al, eds. Global warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty. Geneva: Intergovernmental Panel on Climate Change: Geneva, 2019: 275–311.

3 Watts N, Amann M, Arnell N, et al. The 2019 report of The *Lancet* Countdown on health and climate change: ensuring that the health of a child born today is not defined by a changing climate. *Lancet* 2019; **394:** 1836–78.

4 US National Oceanic and Atmospheric Administrations' National Centers for Environmental Information. Global Climate Report - Annual 2019. January, 2020. https://www.ncdc.noaa.gov/sotc/global/201913 (accessed Sept 21, 2020).

5 Watts N, Adger WN, Agnolucci P, et al. Health and climate change: policy responses to protect public health. *Lancet* 2015; **386:** 1861–914.

6 Costello A, Abbas M, Allen A, et al. Managing the health effects of climate change: *Lancet* and University College London Institute for Global Health Commission. *Lancet* 2009; **373:** 1693–733.

7 International Panel on Climate Change. 2018: Summary for policymakers. In: Masson-Delmotte V, Zhai P, Pörtner HO, et al, eds. Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty. Geneva, Switzerland: World Meteorological Organization, 2018: 1–24.

8 Fitzmaurice C, Abate D, Abbasi N, et al. Global, regional, and national cancer incidence, mortality, years of life lost, years lived with disability, and disability-adjusted life-years for 29 cancer groups, 1990 to 2017: a systematic analysis for the Global Burden of Disease Study. *JAMA Oncol* 2019; **5:** 1749–68.

9 Ferlay J, Shin H-R, Bray F, Forman D, Mathers C, Parkin DM. Estimates of worldwide burden of cancer in 2008: GLOBOCAN 2008. *Int J Cancer* 2010; **127:** 2893–917.

10 Bray F, Ferlay J, Soerjomataram I, Siegel RL, Torre LA, Jemal A. Global cancer statistics 2018: GLOBOCAN estimates of incidence and mortality worldwide for 36 cancers in 185 countries. *CA Cancer J Clin* 2018; **68:** 394–424.

11 Singh GK, Jemal A. Socioeconomic and racial/ethnic disparities in cancer mortality, incidence, and survival in the United States, 1950–2014: over six decades of changing patterns and widening inequalities. *J Environ Public Health* 2017; **2017:** 2819372.

12 Nogueira LM, Yabroff KR, Bernstein A. Climate change and cancer. *CA Cancer J Clin* 2020; published online May 18. https://doi.org/10.3322/caac.21610.

13 Torre LA, Siegel RL, Ward EM, Jemal A. Global cancer incidence and mortality rates and trends—an update. *Cancer Epidemiol Biomarkers Prev* 2016; **25:** 16–27.

14 Smittenaar CR, Petersen KA, Stewart K, Moitt N. Cancer incidence and mortality projections in the UK until 2035. *Br J Cancer* 2016; **115:** 1147–55.

15 Marshall DC, Webb TE, Hall RA, Salciccioli JD, Ali R, Maruthappu M. Trends in UK regional cancer mortality 1991–2007. *Br J Cancer* 2016; **114:** 340–47.

16 Doll R. Health and the environment in the 1990s. *Am J Public Health* 1992; **82:** 933–41.

17 Armstrong BK. Stratospheric ozone and health. *Int J Epidemiol* 1994; **23:** 873–85.

18 Longstreth J. Anticipated public health consequences of global climate change. *Environ Health Perspect* 1991; **96:** 139–44.

19 Urbach F. Potential health effects of climatic change: effects of increased ultraviolet radiation on man. *Environ Health Perspect* 1991; **96:** 175–76.

20 Yury B, Zhang Z, Ding Y, et al. Distribution, inhalation, and health risk of $PM_{2.5}$ related PAHs in indoor environments. *Ecotoxicol Environ Saf* 2018; **164:** 409–15.

21 Jariyasopit N, Tung P, Su K, et al. Polycyclic aromatic compounds in urban air and associated inhalation cancer risks: a case study targeting distinct source sectors. *Environ Pollut* 2019; **252:** 1882–91.

22 Landrigan PJ, Fuller R, Acosta NJR, et al. The *Lancet* Commission on pollution and health. *Lancet* 2018; **391:** 462–512.

23 Matthews-Trigg N, Vanos J, Ebi KL. Climate change and cancer. In: Bernicker EH, ed. Cancer and society. Cham, Switzerland: Springer Nature Switzerland AG, 2019: 11–25.

24 Pope CA 3rd, Coleman N, Pond ZA, Burnett RT. Fine particulate air pollution and human mortality: 25+ years of cohort studies. *Environ Res* 2020; **183:** 108924.

25 Gibson J. Air pollution, climate change, and health. *Lancet Oncol* 2015; **16:** e269.

26 Bernard SM, Samet JM, Grambsch A, Ebi KL, Romieu I. The potential impacts of climate variability and change on air pollution-related health effects in the United States. *Environ Health Perspect* 2001; **109** (suppl 2)**:** 199–209.

27 Malley CS, Henze DK, Kuylenstierna JCI, et al. updated global estimates of respiratory mortality in adults ≥30 years of age attributable to long-term ozone exposure. *Environ Health Perspect* 2017; **125:** 087021.

28 Gao P, Hu J, Song J, et al. Inhalation bioaccessibility of polycyclic aromatic hydrocarbons in heavy $PM_{2.5}$ pollution days: implications for public health risk assessment in northern China. *Environ Pollut* 2019; **255:** 113296.

29 Gao Y, Yang L, Chen J, et al. Nitro and oxy-PAHs bounded in $PM_{2.5}$ and $PM_{1.0}$ under different weather conditions at Mount Tai in Eastern China: sources, long-distance transport, and cancer risk assessment. *Sci Total Environ* 2018; **622–23:** 1400–07.

30 Bandowe BAM, Meusel H. Nitrated polycyclic aromatic hydrocarbons (nitro-PAHs) in the environment—a review. *Sci Total Environ* 2017; **581–582:** 237–57.

31 Hu YJ, Bao LJ, Huang CL, Li SM, Liu P, Zeng EY. Assessment of airborne polycyclic aromatic hydrocarbons in a megacity of South China: spatiotemporal variability, indoor-outdoor interplay, and potential human health risk. *Environ Pollut* 2018; **238:** 431–39.

32 Levy I, Karakis I, Berman T, Amitay M, Barnett-Itzhaki Z. A hybrid model for evaluating exposure of the general population in Israel to air pollutants. *Environ Monit Assess* 2019; **192:** 4.

33 Li J, Yang L, Gao Y, et al. Seasonal variations of NPAHs and OPAHs in $PM_{2.5}$ at heavily polluted urban and suburban sites in North China: Concentrations, molecular compositions, cancer risk assessments, and sources. *Ecotoxicol Environ Saf* 2019; **178:** 58–65.

34 Zhang J, Yang L, Mellouki A, et al. Diurnal concentrations, sources, and cancer risk assessments of $PM_{2.5}$-bound PAHs, NPAHs, and OPAHs in urban, marine, and mountain environments. *Chemosphere* 2018; **209:** 147–55.

35 Park S, Allen RJ, Lim CH. A likely increase in fine particulate matter and premature mortality under future climate change. *Air Qual Atmos Health* 2020; **13:** 143–51.

36 Atkinson RW, Butland BK, Dimitroulopoulou C, et al. Long-term exposure to ambient ozone and mortality: a quantitative systematic review and meta-analysis of evidence from cohort studies. *BMJ Open* 2016; **6:** e009493.

37 Hiatt RA, Brody JG. Environmental determinants of breast cancer. *Annu Rev Public Health* 2018; **39:** 113–33.

38 White AJ, Bradshaw PT, Hamra GB. Air pollution and breast cancer: a review. *Curr Epidemiol Rep* 2018; **5:** 92–100.

39 Yin J, Wu X, Li S, Li C, Guo Z. Impact of environmental factors on gastric cancer: a review of the scientific evidence, human prevention, and adaptation. *J Environ Sci (China)* 2020; **89:** 65–79.

40 Wang H, Sanchez L. Health co-benefits from NDC implementation in China. Winnipeg, MB, Canada: International Institute for Sustainable Development, 2019.

41 Diffey B. Climate change, ozone depletion, and the impact on ultraviolet exposure of human skin. *Phys Med Biol* 2004; **49:** R1–11.

42 Pinault L, Bushnik T, Fioletov V, Peters CE, King WD, Tjepkema M. The risk of melanoma associated with ambient summer ultraviolet radiation. *Health Rep* 2017; **28:** 3–11.

43 Balato N, Ayala F, Megna M, Balato A, Patruno C. Climate change and skin. *G Ital Dermatol Venereol* 2013; **148:** 135–46.

44 Balato N, Megna M, Ayala F, Balato A, Napolitano M, Patruno C. Effects of climate changes on skin diseases. *Expert Rev Anti Infect Ther* 2014; **12:** 171–81.

45 Arnold M, de Vries E, Whiteman DC, et al. Global burden of cutaneous melanoma attributable to ultraviolet radiation in 2012. *Int J Cancer* 2018; **143:** 1305–14.

46 Kaffenberger BH, Shetlar D, Norton SA, Rosenbach M. The effect of climate change on skin disease in North America. *J Am Acad Dermatol* 2017; **76:** 140–47.

47 Lin MJ, Torbeck RL, Dubin DP, Lin CE, Khorasani H. Climate change and skin cancer. *J Eur Acad Dermatol Venereol* 2019; **33:** e324–25.

48 van Dijk A, Slaper H, den Outer PN, et al. Skin cancer risks avoided by the Montreal Protocol—worldwide modeling integrating coupled climate-chemistry models with a risk model for UV. *Photochem Photobiol* 2013; **89:** 234–46.

49 Newman PA, McKenzie R. UV impacts avoided by the Montreal Protocol. *Photochem Photobiol Sci* 2011; **10:** 1152–60.

50 Andersen LK, Hercogová J, Wollina U, Davis MD. Climate change and skin disease: a review of the English-language literature. *Int J Dermatol* 2012; **51:** 656–61.

51 van der Leun JC, de Gruijl FR. Climate change and skin cancer. *Photochem Photobiol Sci* 2002; **1:** 324–26.

52 van der Leun JC, Piacentini RD, de Gruijl FR. Climate change and human skin cancer. *Photochem Photobiol Sci* 2008; **7:** 730–33.

53 Lucas RM, Yazar S, Young AR, et al. Human health in relation to exposure to solar ultraviolet radiation under changing stratospheric ozone and climate. *Photochem Photobiol Sci* 2019; **18:** 641–80.

54 Piacentini RD, Della Ceca LS, Ipiña A. Climate change and its relationship with non-melanoma skin cancers. *Photochem Photobiol Sci* 2018; **17:** 1913–17.

55 Bharath AK, Turner RJ. Impact of climate change on skin cancer. *J R Soc Med* 2009; **102:** 215–18.

56 Coates SJ, Enbiale W, Davis MDP, Andersen LK. The effects of climate change on human health in Africa, a dermatologic perspective: a report from the International Society of Dermatology Climate Change Committee. *Int J Dermatol* 2020; **59:** 265–78.

57 Makin J. Implications of climate change for skin cancer prevention in Australia. *Health Promot J Austr* 2011; **22:** S39–41.

58 Wright CY, du Preez DJ, Millar DA, Norval M. The epidemiology of skin cancer and public health strategies for its prevention in southern Africa. *Int J Environ Res Public Health* 2020; **17:** e1017.

59 Wright CY, Norval M, Kapwata T, et al. The incidence of skin cancer in relation to climate change in South Africa. *Atmosphere (Basel)* 2019; **10:** 634.

60 Harari Arjona R, Piñeiros J, Ayabaca M, Harari Freire F. Climate change and agricultural workers' health in Ecuador: occupational exposure to UV radiation and hot environments. *Ann Ist Super Sanita* 2016; **52:** 368–73.

61 World Cancer Research Fund International. Diet, nutrition, physical activity, and cancer: a global perspective. https://www.wcrf.org/dietandcancer (accessed Sep 21, 2020).

62 Springmann M, Mason-D'Croz D, Robinson S, et al. Global and regional health effects of future food production under climate change: a modelling study. *Lancet* 2016; **387:** 1937–46.

63 Kang JX. The omega-6/omega-3 fatty acid ratio in chronic diseases: animal models and molecular aspects. *World Rev Nutr Diet* 2011; **102:** 22–29.

64 Sarfati D, Dyer R, Sam FA, et al. Cancer control in the Pacific: big challenges facing small island states. *Lancet Oncol* 2019; **20:** e475–92.

65 Cotty PJ, Jaime-Garcia R. Influences of climate on aflatoxin producing fungi and aflatoxin contamination. *Int J Food Microbiol* 2007; **119:** 109–15.

66 Liew WP, Mohd-Redzwan S, Than LTL. Gut microbiota profiling of aflatoxin B1-induced rats treated with *Lactobacillus casei* Shirota. *Toxins (Basel)* 2019; **11:** E49.

67 Battilani P, Toscano P, Van der Fels-Klerx HJ, et al. Aflatoxin B1 contamination in maize in Europe increases due to climate change. *Sci Rep* 2016; **6:** 24328.

68 Dietz WH. Climate change and malnutrition: we need to act now. *J Clin Invest* 2020; **130:** 556–58.

69 Miner KR, Bogdal C, Pavlova P, Steinlin C, Kreutz KJ. Quantitative screening level assessment of human risk from PCBs released in glacial meltwater: Silvretta Glacier, Swiss Alps. *Ecotoxicol Environ Saf* 2018; **166:** 251–58.

70 Miner KR, Kreutz KJ, Jain S, Campbell S, Liljedahl A. A screening-level approach to quantifying risk from glacial release of organochlorine pollutants in the Alaskan Arctic. *J Expo Sci Environ Epidemiol* 2019; **29:** 293–301.

71 Regli S, Chen J, Messner M, et al. Estimating potential increased bladder cancer risk due to increased bromide concentrations in sources of disinfected drinking waters. *Environ Sci Technol* 2015; **49:** 13094–102.

72 Los Angeles Times. Cancer-causing chemical taints water after deadly Paradise wildfire. April 18, 2019. https://www.latimes.com/local/lanow/la-me-ln-benzene-poisoning-paradise-20190418-story.html (accessed Sept 21, 2020).

73 Tabuchi HPN, Migliozzi B, Lehren AW. Floods are getting worse, and 2,500 chemical sites lie in the water's path. Feb 6, 2018. https://www.nytimes.com/interactive/2018/02/06/climate/flood-toxic-chemicals.html?mtrref=www.google.com&gwh=2C5D2487895C81FCAC5CA3AAF5AC7998&gwt=pay&assetType=REGIWALL (accessed Sept 21, 2020).

74 Low AJ, Frederix K, McCracken S, et al. Association between severe drought and HIV prevention and care behaviors in Lesotho: a population-based survey 2016–2017. *PLoS Med* 2019; **16:** e1002727.

75 Blaser MJ. Theodore E Woodward award: global warming and the human stomach: microecology follows macroecology. *Trans Am Clin Climatol Assoc* 2005; **116:** 65–75.
76 Blum AJ, Hotez PJ. Global "worming": climate change and its projected general impact on human helminth infections. *PLoS Negl Trop Dis* 2018; **12:** e0006370.
77 Salas RN, Jha AK. Climate change threatens the achievement of effective universal healthcare. *BMJ* 2019; **366:** l5302.
78 Man RX, Lack DA, Wyatt CE, Murray V. The effect of natural disasters on cancer care: a systematic review. *Lancet Oncol* 2018; **19:** e482–99.
79 Hantel A, Abel GA. An action plan for environmentally sustainable cancer care. *JAMA Oncol* 2020; **6:** 469.
80 Rennert G. Colorectal cancer screening: will global warming affect the accuracy of FIT testing? *Gut* 2010; **59:** 1451–52.
81 Zorrilla CD. The view from Puerto Rico—hurricane Maria and its aftermath. *N Engl J Med* 2017; **377:** 1801–03.
82 Mayer DK, McCabe M. Climate change and cancer care. *Clin J Oncol Nurs* 2013; **17:** 231–32.
83 Devi S. Cyclone Idai: 1 month later, devastation persists. *Lancet* 2019; **393:** 1585.
84 Bell SA, Banerjee M, Griggs JJ, Iwashyna TJ, Davis MA. The effect of exposure to disaster on cancer survival. *J Gen Intern Med* 2020; **35:** 380–82.
85 Ryan BJ, Franklin RC, Burkle FM Jr, et al. Defining, describing, and categorizing public health infrastructure priorities for tropical cyclone, flood, storm, tornado, and tsunami-related disasters. *Disaster Med Public Health Prep* 2016; **10:** 598–610.
86 Nogueira LM, Sahar L, Efstathiou JA, Jemal A, Yabroff KR. Association between declared hurricane disasters and survival of patients with lung cancer undergoing radiation treatment. *JAMA* 2019; **322:** 269–71.
87 Hallegatte SBM, Bonzanigo L, Fay M, et al. Shock waves: managing the impacts of climate change on poverty. Washington, DC: World Bank, 2018.
88 Rigaud KK, de Sherbinin A, Jones B, et al. Groundswell: preparing for internal climate migration. Washington, DC: World Bank, 2018.
89 El Saghir NS, Soto Pérez de Celis E, Fares JE, Sullivan R. Cancer care for refugees and displaced populations: Middle East conflicts and global natural disasters. *Am Soc Clin Oncol Educ Book* 2018; **38:** 433–40.
90 Markandya A, Sampedro J, Smith SJ, et al. Health co-benefits from air pollution and mitigation costs of the Paris Agreement: a modelling study. *Lancet Planet Health* 2018; **2:** e126–33.
91 Haines A. Health co-benefits of climate action. *Lancet Planet Health* 2017; **1:** e4–5.
92 Martens WJ. Health impacts of climate change and ozone depletion: an ecoepidemiologic modeling approach. *Environ Health Perspect* 1998; **106** (suppl 1)**:** 241–51.
93 Hart J. Association between air temperature and cancer death rates in Florida: an ecological study. *Dose Response* 2015; **13:** dose-response.14-024.Hart.
94 Xu R, Li S, Guo S, et al. Environmental temperature and human epigenetic modifications: a systematic review. *Environ Pollut* 2020; **259:** 113840.