A brief review of global climate change and the public health consequences

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Background
Global climate change (GCC) will have an enormous impact on public health in the 21st century. Evidence clearly implicates the use of fossil fuels and the resultant anthropogenic greenhouse gases as the major source of GCC.

Objectives
This paper seeks to examine briefly the association between fossil fuels and GCC, the consequent environmental changes and the predicted public health effects.

Discussion
Complex and interrelated climate changes are forecast to present immense challenges, including increased morbidity and mortality, arising from heatwaves, extreme weather events, infectious and non-communicable diseases. The subsequent health effects, modulated by socioeconomic determinants, will be distributed inequitably primarily to vulnerable populations, largely in the tropics. A response to GCC is urgently required, involving strategies to mitigate and adapt to GCC. Not only will general practitioners be managing health conditions caused by GCC, but they are also well placed in the community to advocate for GCC mitigation.

THE CURRENT DEBATE about energy policy in Australia is firmly centred on energy costs and reliability. These are prominent issues for public health, given the morbidity and mortality related to heatwaves and cold weather, especially in disadvantaged communities. However, this policy discourse neglects the more significant health effects arising from global climate change (GCC) associated with fossil energy use.

GCC is potentially the defining challenge to public health in the 21st century.[1] General practitioners (GPs), who are at the frontline of care for patients affected by GCC, must also advocate for health outcomes in the public debate concerning GCC – as the World Health Organization (WHO) asserts, 'health professionals have a major responsibility to act as advocates for health at all levels in society'.[2] Consequently, this paper seeks to briefly examine the genesis of GCC and outline the predicted public health effects of GCC.

The science of anthropogenic GCC

Life on earth is dependent on naturally occurring greenhouse gases (GHGs), especially methane and carbon dioxide (CO_2), which are modulated by a complex carbon cycle. Without these GHGs trapping heat, the earth's surface temperature would be, on average, 35°C colder.[3] The industrial world has tampered with this vital cycle by using the carbon trapped in life that has not decayed to power their industries and development. Since the 1960s, when it was estimated that doubling the CO_2 content in the atmosphere would raise atmospheric average temperatures by 2°C,[4] evidence has been accumulating linking increased GHGs to increased global average temperatures.[5–8] This century, each monthly average global land and ocean surface temperature has exceeded the average temperatures for the 20th century,[9] and recent patterns of climate change are unlike past cycles.[7,8]

Many studies, some summarised by the Intergovernmental Panel on Climate Change (IPCC), clearly conclude that it is extremely likely that anthropogenic GHG emissions are the dominant reason for global warming since the mid-20th century.[5,6,10] An Australian study estimated that with anthropogenic GHGs removed, the chance of the climate pattern observed over the last 20 years occurring is 1:100,000.[9]

Predictions about the future effects of GCC are more difficult, given the intricacies of local climates, the complex interrelationships of changes and the varying scenarios of GHG emission. For instance, the changes are not uniform, with land temperature found to be rising more rapidly in higher latitudes.[11] Nevertheless, environmental outcomes of GCC would have substantial effects on societies, economies and health (Table 1).

The public health impact of GCC

The likely public health impact of GCC is vast; already in 2000, GCC was estimated to have caused 150,000 deaths and 5.5 million lost disability-adjusted life years (DALYs) per year.[12] The full extent, summarised in Table 2, is beyond the scope of this paper and is presented in more comprehensive studies.[1,13–15] Not all the changes will be adverse. Cold-related mortality and morbidity will decrease in some higher latitude populations; however, as Table 2 illustrates, this will be

Table 1. Environmental impact of global climate change[5]

	Climate changes	Likely negative environmental outcomes
Carbon cycle processes	Increasing greenhouse gases in atmosphere, initially slowed by carbon dioxide (CO_2) trapping in ocean with consequent acidification	• Changes and damage to ocean biodiversity, loss of coral • Deteriorating air quality with conditions favouring ozone production in troposphere, increasing smog • Further release of CO_2 and methane from permafrost melt in northern hemisphere
Land temperature	Increasing average temperatures, with more very warm days, fewer cold days and increased frequency and severity of heatwaves	• Decreased agricultural yield, changes in disease vector prevalence with increasing penetration to higher altitudes and latitudes • Increased pollen production in colder areas • Greater survival and proliferation of microbes with possible effect on water and food quality
Ocean temperature	Deeper penetration of heat	• Ocean biome affected • Ocean currents changed, with various possible effects on climate control[3]
Cryosphere	Arctic ice to decrease by 43–95% in spring and non-Arctic glaciers predicted to shrink by between 15% and 55% by end of 21st century	• Sea level rise • Decreased salinity in northern hemisphere affecting currents and amount of water vaporisation • Loss of Arctic habitat
Sea level	Average sea level rise by the year 2100 is 0.52–0.98 m, with a rate during 2081 to 2100 of 8–16 mm/year	• Loss of land: arable and liveable • Increased storm surges • Coastal aquifer salinity
Hydrology	Increasing sea temperatures lead to increasing water vapour for storms and increased precipitation	• Increased frequency and severity of floods and tropical cyclones • El Niño–Southern Oscillation dominant in Pacific • Monsoon region extended
	Greater extremes in wet and dry regions and seasons, increasing drought, especially in rural areas[36]	• Increased severity and frequency of drought and bushfires

overshadowed by the numerous serious adverse health outcomes.

Predicting the future public health effects of GCC is problematic but is derived from evidence that includes observations under the adverse climatic conditions expected, and biological or statistical models. This is further complicated by the presence of other health determinants interacting with and modulating the climate change effects. For example, the trend towards urbanisation and the effects of local climates (urban heat islands) amplify the impact of heatwaves, while poverty impairs the ability of a population to adapt.[16] Loss of biodiversity and predators through habitat destruction augments the effect of GCC-induced survival of vectors, such as the ticks causing Lyme disease.[14]

The human health effects of GCC are also interactive and more complex, as exemplified by vector ecology. Warmer temperature within the survival range of vectors will favour transmission of pathogens by increasing lifespan, reproduction, biting activity, the rate at which pathogens mature within the vector, and the latitude and altitude of subsistence.[17] While increased precipitation increases the availability of breeding grounds for malaria-carrying *Anopheles* mosquitos, drought and alternate water storage would expand the habitat for *Aedes* mosquitoes that carry dengue, chikungunya and Zika.[17–20] Finally, increased temperatures may increase toxicity and bioavailability of toxins that could have an impact on the host defences, and human migration will increase exposure of larger, less-immune populations.[15,21,22]

Despite the difficulties of modelling such changes, diseases such as malaria, dengue, yellow fever, Zika and other flaviviruses are expected to increase in incidence, especially adjacent to current endemic areas.[17,19,21] Similarly, tick, sandfly and snail survival and expanded geographic range will lead to increased incidence of tick-borne encephalitis, typhus, Lyme disease, leishmaniasis and schistosomiasis.[17,21] Malaria, affecting about 50% of the world's population on a daily basis,[23] is projected to increase to 60% and to favour seasonal transmission,

Table 2. Impact of global climate change (GCC) on human health

GCC health hazards	Likely resultant adverse health outcomes
Extreme heat: hotter days, more extreme and frequent heatwaves	Heat-related mortality and morbidity increase (mainly pre-existing cardiovascular and respiratory disease),[34,52–58] especially in vulnerable populations such as elderly,[55,56] children,[56] mentally unwell[59]
Extreme weather events: more severe and frequent floods and tropical cyclones	Injuries and deaths, infectious diseases (eg diarrhoeal),[60,61] exposure to pollutants,[62] and subsequent mental health issues[63,64]
Increased precipitation: increasing entry of human and animal into waterways and drinking water supplies	Increased water-borne diseases (eg typhoid, cryptosporidiosis, campylobacter, leptospirosis)[60,65]
Increase in temperature: favouring pathogen proliferation	Increased food-borne illness and diarrhoeal diseases (eg salmonella, campylobacter, cholera, harmful algal blooms)[30,60,65–69]
Climate changes to vector ecology: increasing proliferation, increasing biting activity, increasing latitude and altitude habitat	Increased exposure and infections with arboviruses and other vector disease such as: malaria, dengue, yellow fever, Zika, Ross River fever, borreliosis, tick-borne encephalitis, typhus, leishmaniasis, filariasis and Chagas disease[17–20,24,27,70–73]
Climate-related migration of reservoirs and hosts: bringing both in closer proximity	Increased exposure of populations with lower immunity to disease[71]
Drought, crop yields and altered land availability: decreasing food security	Malnutrition[74,75]
Air pollution: increased particulate matter (mostly not due directly to GCC but related to burning fossil fuels), ozone and allergens	Respiratory tract infections and exacerbation of chronic diseases (eg cardiovascular diseases, chronic obstructive pulmonary disease and asthma)[31,32,33]
Changes to ocean temperature and acidity: migration and loss of fish stock	Malnutrition, especially in coastal areas of low-income countries[75]
Sea level rise: forced migration and competition for dwindling resources	Conflict, mental health issues, health-related problems of climate asylum seekers[15,76]

with the implication of greater epidemics.[24] In 2017 there were reports of local transmission of malaria and chikungunya in Italy, an area declared malaria-free by WHO in 1970.[25,26] Although the exact cause is uncertain, this shows a vulnerability to the changes presented by GCC.

Vector-borne diseases, especially those caused by arboviruses, are also estimated to increase in Australia as a result of GCC.[1] Increasing temperatures,[27] inter-annual variations in climatic and environmental conditions,[15] and tidal variations associated with GCC[1] all favour an increased incidence and geographic distribution of Ross River fever. Similarly, dengue is likely to show an increased incidence and geographic distribution,[15,17,20,28] despite some calls for caution on interpretations.[29]

The incidence of enteric illnesses, especially salmonellosis, increases linearly with rising ambient temperature.[15,30] This suggests that GCC would be associated with a larger burden from food-borne illnesses, which affected an estimated 5.4 million Australians and cost the economy $1.2 billion in 2005.[16]

Non-communicable diseases, especially cardiovascular and respiratory diseases, are already leading causes of global burden of disease and are set to increase further with GCC, principally through air pollution and heatwaves. Burning fossil fuels, in addition to its role in causing GCC, is largely responsible for the health impact of ambient air pollution – an estimated 76 million DALYs globally in 2012.[31] Higher ambient temperatures amplify the impact of particulate matter and increase ozone present in the troposphere.[18,32] GCC will also lead to higher levels of aeroallergens, especially in more temperate regions, exacerbating asthma and allergic conditions that are already common in Australia.[33]

Heatwaves will become more prevalent and more extreme in Australia, with estimated summer temperatures in 2100 to peak over 50°C.[1] Heatwaves have already been shown to increase mortality; for instance, there was a 23% increase in non-external deaths in a Brisbane heatwave in 2004[34] and a 23% increase in cardiovascular mortality due to a heatwave in Victoria in 2009.[16] Given a moderate GHG emission scenario, annual mortality from excess heat in capital cities is predicted to rise by 50%.[15]

Australia is one of the most arid continents on this planet, and drought-prone areas have become even more arid since the 1970s.[35] Droughts are expected to become more severe with GCC, especially in rural areas, causing adverse effects for the agricultural industry, food and water security, and mental health, especially of rural Australians.[16] Accompanying this is an escalation in the severity and frequency of bushfires, again mainly in rural areas.[15] The possible impact is demonstrated by the 'Black Saturday' bushfires in Victoria in 2009 where 173 people died, 2500 properties were lost and over 5000 livestock were destroyed.[16] At the other extreme, there will be an increase in the frequency and magnitude of one of Australia's most common disasters – floods.[36]

Inequity in GCC

The extent of public health outcomes in Australia due to GCC pales in comparison to the expected problems that will be faced by low- and middle-income countries (LMICs). Increased vulnerability of populations in LMICs may be related to: greater habitation in high-risk areas, such as flood plains and coastal zones;[18,37,38] greater exposure to rising temperatures and extreme weather events, as the majority are already in a tropical climate;[39–41] greater exposure to infectious disease – for example, the per capita mortality rate from vector-borne disease is currently hundreds of times greater in LMICs when compared with high-income countries;[17] and already poorer water and sanitation in LMICs and the lack of infrastructure and purchasing power leading to water scarcity[42] and diminished food security.[40]

Poorly resourced communities are less insulated against GCC, with factors such as an inadequate public-health infrastructure; a restricted economy that will be damaged much more, proportionately, than in industrialised countries;[43] fewer risk-sharing systems such as insurance;[18] and governance that is often ineffective at delivering resources to prevent human suffering.[14]

In Australia, despite being a high-income country, much of what is problematic for LMICs is true for Aboriginal and Torres Strait Islander communities, especially in tropical Australia. Factors that increase their vulnerability to GCC are: inadequate housing; habitation in areas with vectors; decreased purchasing power; inadequate health and energy infrastructure; decreased water security; and lack of food security that contributes to an already elevated level of chronic illness.[44,45] GCC will increasingly affect the health of Aboriginal and Torres Strait Islander communities and, along with historical and socioeconomic determinants, multiply the challenges to closing the Aboriginal and Torres Strait Islander health gap.

Table 3. Strategies to mitigate and adapt to global climate change

Mitigation	
Fuels and energy	• Closing of fossil fuel energy stations • International policies that set greenhouse gas and temperature targets – Paris Agreement • National clean energy targets • Technology for carbon capture[1,13]
Land use	• Reforestation • Sustainable development[1,13]
Community development and the built environment	• Building low-carbon cities • Informing and assisting state governments to improve public transport with greater use of renewable energy and efficient use of energy • Informing and assisting local governments to encourage use of renewable energy and more efficient use of energy • Informing and assisting communities to adopt lifestyles that demand less energy and use energy more efficiently[1,13]
Adaptation	
Extreme weather events	• Improved forecasting • Predicting possible health outcomes • Triggering effective and timely response plans, targeting vulnerable populations • Communicating prevention responses • Updating disaster management plans[35,77–79]
Heatwaves	• Improved health worker training • Urban planning: increasing urban green spaces, designing social facilities, schools, public spaces, and public transport to be more climate-responsive • Public health infrastructure heatwave early warning systems (HEWS), especially for the most vulnerable populations[80–82]
Floods and storms	• Infrastructure development such as reservoirs and floodways • Development policies, zoning laws and building codes accommodating for possible flooding • Emergency readiness, flood forecasting, and recovery post-flood including risk communication on infections, boiling water, and other health issues[77]
Food insecurity	• Improved local ecosystem management • Good governance and international mechanisms to enhance food security in vulnerable populations • Increased investments in rural and water infrastructure • Enhanced international partnerships, especially in emergency responses to food crises[83,84]
Infectious diseases	• Improved public health capacity in all nations, especially in vulnerable area • Research and support for determinants of health, such as education and poverty • Improved surveillance and monitoring • Vaccination • Effective and rapid response to emerging infectious diseases[18,85]

Responses to GCC

Considering the health effects and the inequitable burden on the poorer populations, all health professionals are called to respond to GCC. This is especially true for those from high-income countries, given intuitive, justice-based and 'polluter pays' ethical frameworks.[43] This must be primarily through mitigation of GCC via lower fossil fuel dependence; more efficient use of energy in industry, transport and communities; and lower carbon footprint 'built environments' (Table 3). However, the effects of GCC are already present and growing and, therefore, strategies for adaptation to GCC are crucial.

These strategies (Table 3) mainly occur upstream, though good clinical care of the chronic illnesses and infections already discussed is also required. This includes educating patients to take appropriate action during heatwaves: avoid alcohol, wear light clothing, use or visit places with air conditioning, remain well hydrated, and check on vulnerable people in their communities.[46] It also involves contributing to the responses to natural disasters, such as bushfires, particularly assisting the community in recovery.

Conclusion

Internationally, in 2016, the Paris Agreement set targets for GHG emissions that hold the global average temperatures to well below 2°C above pre-industrial levels.[47] Australia, a leading producer and one of the highest per capita consumers of fossil fuels,[48] is a signatory to this Agreement. Despite this, and the Finkel Report concluding that secure energy is possible with reduced GHG emissions,[49] the federal government decreased renewable energy targets in 2015[50] and continues to approve new coal mines.[51]

GPs, as well as preventing and treating the many illnesses associated with GCC, are well placed to advocate for changes to policies that affect GCC. Individually, in community groups, or collectively through professional bodies such as The Royal Australian College of General Practitioners, Australian Medical Association, Public Health Association of Australia, or the International Society of Doctors for the Environment, immediate action is vital. This advocacy will not only address the future public health consequences of GCC, it will also have an impact on current health issues through decreased air pollution, and improved penetration and quality of health delivery to vulnerable communities locally and globally.

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