NIH Public Access
Author Manuscript
Prev Med. Author manuscript; available in PMC 2015 April 01.

Published in final edited form as:
Prev Med. 2015 January ; 70: 69–75. doi:10.1016/j.ypmed.2014.11.013.

Climate change, human health, and epidemiological transition

Bruce Barrett[1], **Joel W. Charles**, and **Jonathan L. Temte**
University of Wisconsin School of Medicine and Public Health, Department of Family Medicine, University of Wisconsin—Madison, 1100 Delaplaine Street, Madison, WI 53715, United States

Abstract

The health of populations depends on the availability of clean air, water, food, and sanitation, exposure to pathogens, toxins and environmental hazards, and numerous genetic, behavioral and social factors. For many thousands of years, human life expectancy was low, and population growth was slow. The development of technology-based civilizations facilitated what Abdel Omran called "epidemiological transition," with increasing life expectancy and rapid population growth. To a large extent, the spectacular growth of human populations during the past two centuries was made possible by the energy extracted from fossil fuels. We have now learned, however, that greenhouse gases from fossil fuel combustion are warming the planet's surface, causing changes in oceanic and atmospheric systems, and disrupting weather and hydrological patterns. Climate change poses unprecedented threats to human health by impacts on food and water security, heat waves and droughts, violent storms, infectious disease, and rising sea levels. Whether or not humanity can reduce greenhouse gas emissions quickly enough to slow climate change to a rate that will allow societies to successfully adapt is not yet known. This essay reviews the current state of relevant knowledge, and points in a few directions that those interested in human health may wish to consider.

Keywords

Climate change; Environment; Epidemiology; Global warming; Population health

In his seminal 1971 paper "The epidemiological transition," Abdel Omran put forth a conceptual framework linking the many facets of epidemiology with the forces behind population dynamics, emphasizing the changing nature of structural influence (Omran, 1971). At that point in human history, clear and convincing evidence had emerged documenting a "transition in which degenerative and man-made diseases displace pandemics of infection as the primary causes of morbidity and mortality." Around the same time, scientists were beginning to report that human emissions of greenhouse gases were causing global warming and climate change (Benton, 1970; Gast, 1971; Manabe and Wetherald, 1975).

[1]bruce.barrett@fammed.wisc.edu (B. Barrett). Fax: +1 608 263 5813.

Conflict of interest statement

The authors declare that there are no conflicts of interests.

Omran divided human history into three major epidemiological epochs. The first, or "Age of Pestilence and Famine," lasted for thousands of years and was characterized by cyclic patterns of localized population growth ended by major die-offs, often precipitated by war, civilization collapse, and/or epidemic infection. In the second "Age of Receding Pandemics" Omran wrote that "mortality declines progressively; and the rate of decline accelerates as epidemic peaks become less frequent or disappear." In Omran's third epoch, the "Age of Degenerative and Man-Made Diseases," "mortality continues to decline and eventually approaches stability at a relatively low level. The average life expectancy at birth rises gradually until it exceeds 50 years. It is during this stage that fertility becomes the crucial factor in population growth."

For more than a century, knowledge regarding "degenerative and man-made diseases" has increased at a dizzying pace. The era of using science to identify and respond to human-engendered disease arguably began when John Snow in 1854 traced the source of a London cholera epidemic and then removed the Broad Street pump handle to limit further contagion (Koch and Denike, 2009; Paneth, 2004; Tulchinsky, 2010). Not long afterwards, work by Louis Pasteur (Bordenave, 2003) and others led to a remarkably broad and detailed understanding of infectious disease, much of which was caused or exacerbated by population growth, urbanization, and crowding. These discoveries provided rationale for large scale potable water, sanitation and public health systems, which in turn facilitated even more rapid population growth in the world's emerging urban centers (Szreter, 2003).

More recently, the cardiovascular disease epidemic has been investigated and addressed at multiple levels, with several proven strategies to normalize blood pressure, prevent clots, and reduce cholesterol. For several cancers, useful screening and/or effective treatments are now available. Environmental, occupational and behavioral strategies have been even more effective. Science demonstrating tobacco's ill effects was followed by widespread and effective smoking cessation campaigns. Seat belts, safer automobiles and better roadways have greatly reduced motor vehicle casualties. Water and air pollution have improved in many locales, with measurable improvements in cardio-respiratory morbidity and mortality. Mostly missing from the medicine and public health discourse, however, has been the realization that massive-scale human activity is radically altering the atmosphere and surface of the planet, and that the basic functionality of our life-sustaining ecosystem can no longer be taken for granted.

It took several million years for anthropoid apes to evolve to anatomically modern human form, and then another 400 centuries before our *Homo sapiens sapiens* ancestors began to show their prowess. Following the advent of agriculture around 10,000 years ago, populations began to increase substantively, spreading out across the globe, forming cities, kingdoms, and civilizations. By 1800, there were approximately a billion (1,000,000,000) people on the planet. This doubled to around 2 billion by 1922, 4 billion by 1974, and 7 billion today. New technologies and systems of production led to rapid and widespread developments in agriculture, transportation and sanitation, with ever-increasing numbers of people living longer, more productive, and more consumptive lives.

The past two centuries of explosive population growth were facilitated in large part by the burning of fossil fuels. Mechanization of agriculture, combined with increasing agrochemical inputs, not only fertilizers, but also pesticides, allowed huge increases in crop productivity, which in turn fueled population growth. Exploitation of coal, oil, and natural gas yielded vast and rapid systems of transport, electrical power, and a globalized economy of relatively inexpensive and widely available products, services, and information exchange. This modern era of explosive growth, however, cannot continue unabated, given the finite nature of the resources and the ecological threats that unrestrained consumption poses. Having survived (so far) the specter of nuclear war, humanity is now facing the fundamental contradiction of continued growth trajectories in the face of resource and ecosystem limitations. If we successfully respond to these challenges and transition to a sustainable future, humanity may enter a new age, characterized by much more prudent use of energy, among other things. These ideas are not entirely new. In 1798, Reverend Thomas Robert Malthus noted that finite resources, such as arable land, would eventually be overcome by sustained population growth: "The power of population is indefinitely greater than the power in the earth to produce subsistence for man (Malthus, 1798)."

Similar ideas have been put forth many times since, most notably in 1968 by Paul and Ann Ehrlich in *The Population Bomb* (Ehrlich, 1968) and then in 1972 in *The Limits to Growth* (Meadows et al., 1972) by Donella Meadows and colleagues from The Club of Rome, who showed with then state-of-art computer modeling that finite resources are incompatible with unlimited economic and population growth. Similar notions were initially explored in the ecological literature by writers such as Pianka (1970) and MacArthur and Wilson (1967) who showed that reproduction rates and longevity dynamics combined with environmental constraints, such as availability of food and water, lead to "boom and bust" cycles, and, occasionally, to species extinction.

What is relatively new to this discourse, however, is the realization that human-emitted greenhouse gases are warming the planet, melting the ice caps, raising the oceans, and increasing the frequency of droughts, floods and extreme weather events. There is no longer any reasonable doubt that global warming is occurring, and that this is due primarily to human activities (IPCC Working Group 1, 2013; IPCC Working Group 2, 2014; National Academy of Sciences, 2014; National Climate Assessment and Development Advisory Committee, 2014). There is also very little doubt that ensuing changes in climatic patterns will lead to myriad adverse outcomes, including heat waves, droughts, and increased frequency and violence of major weather events (Honda et al., 2014; Kravchenko et al., 2013; Lane et al., 2013; Stanke et al., 2013). These will in turn accelerate the already monumental and tragic loss of biodiversity, (Cardinale et al., 2012; Hooper et al., 2012; Mayhew et al., 2008; Pimm et al., 2014; World Resources Institute, 2005) and will promote the spread of infectious diseases such as malaria and gastrointestinal infections (De Luca and Giraldi, 2011; Murray et al., 2013; Patz and Reisen, 2001; Ramasamy and Surendran, 2011). The billion or so people living on low-lying islands and coastlines will need to immigrate, adapt, or perish (McMichael et al., 2012a). This will place pressure not only on those most directly threatened, but on political and economic systems in neighboring countries, and indeed, on all societies. Health outcomes, psychosocial stresses and behavioral responses cannot be predicted with confidence, but the broad outlines are extremely concerning (Patz et al., 2014).

Since “The epidemiological transition” was first published in 1971, the scientific understanding of anthropogenic global warming has matured. While some details are still emerging, the broad outlines are incontrovertible. The burning of fossil fuels has released hundreds of gigatons of greenhouse gases, most notably carbon dioxide (CO_2), which has increased in atmospheric concentration from pre-industrial levels of 280 parts per million (ppm) to more than 400 ppm today (IPCC Working Group 1, 2014). This has already contributed to a mean surface temperature increase of 0.9 °C, and an average ocean surface rise of more than 20 cm (Intergovernmental Panel on Climate Change, 2007). Current projections suggest that average global temperatures will rise to 2 to 6 °C above the levels in which humanity evolved (IPCC Working Group 1, 2014). Even the most conservative projections conclude that this will constitute the most rapid change of atmospheric composition and global temperature ever occurring in our planet's 4.5 billion year history (National Research Council, 2013a). It will also accelerate what is already by far the worst wave of plant and animal extinctions our planet has experienced, with approximately 3 species disappearing each hour and a third of all vertebrates disappearing in less than 50 years, an extinction rate of approximately 1000 times evolutionary background averages (Cardinale et al., 2012; Hooper et al., 2012; Mayhew et al., 2008; Pimm et al., 2014; World Resources Institute, 2005).

Following the advice of numerous scientific bodies, the 2009 Copenhagen Accord called for policies that would limit average planetary warming to no more than 2.0 °C (Ramanathan and Xu, 2010). Current best estimates conclude that no more than an additional 400 to 800 gigatons of CO_2 can be added to the atmosphere if we are to have a reasonable chance of staying within this limit (IPCC Working Group 1, 2014;Meinshausen et al., 2009). Burning all proven coal, oil and gas reserves, however, would produce around 2800 gigatons, likely leading to temperature rises of 3 to 6 °C (Meinshausen et al., 2009). Warming of this magnitude could trigger positive feedback loops pushing atmospheric and oceanic systems past a series of crucial tipping points (Hansen et al., 2013; National Research Council, 2013a). As the ice cover melts, less of the sun's energy is reflected, increasing heating effects. Melting of the northern tundra would release vast quantities of methane and other greenhouse gases, further accelerating the process. Conservative models project that water from melting of the Greenland and Antartic ice sheets will combine with thermal expansion to yield sea level rises of 200–600 cm by the year 2100 (IPCC Working Group 1, 2014). Adding in tipping points and positive feedback loops, we may be looking at ocean surface rises of 10mor more by the middle of next century (Hansen et al., 2013; Joughin et al., 2014; Rahmstorf, 2010; Rignot et al., 2014). Thirteen of the world's 20 largest cities are located on a coastline. More than 2 billion people live within 60 miles of the sea. The scale and complexity of relocation and adaptation efforts needed for sustainable survival in such a scenario are difficult to forecast. Current best estimates project the number of environmental refugees in the tens to hundreds of millions within the next few decades (McMichael et al., 2012a). In the longer term, global warming victims and refugees could number in the billions, as seas would rise by more than 200 ft if all the ice melts (Folger, 2013).

The broad outlines of the effect of global warming on human health are only beginning to emerge (Costello et al., 2011; Ebi, 2011; McMichael et al., 2012b; Patz et al., 2007, 2014; Rapley, 2012). One authoritative study published in the Lancet in 2009 (Costello et al., 2009) described six categories related to projected health effects: 1) changing patterns of disease, 2) food, 3) water and sanitation, 4) shelter and human settlements, 5) extreme weather events, and 6) migration. While useful, these categories are overlapping and interactive. Changing climatic patterns are causing both droughts (Battisti and Naylor, 2009; Stanke et al., 2013) and floods, (Lane et al., 2013; Woodward et al., 2013) directly impacting potable water availability (Bates et al., 2008) and agricultural productivity (Lobell and Gourdji, 2012). Extreme weather events are dangerous and costly, and may threaten water and sewage systems, (Lane et al., 2013; Schmeltz et al., 2013) reduce agricultural output, (Battisti and Naylor, 2009; Friel et al., 2009; Lobell et al., 2008) and damage housing and economic infrastructure (Lane et al., 2013; Sauerborn and Ebi, 2012).Malnutrition and poor sanitation lead to more frequent and virulent outbreaks of infectious disease. Ecosystem changes can increase prevalence of vectors and reservoir hosts, which when combined with decreased human host resistance, can lead to deadly epidemics of cholera, dengue, cryptosporidia, West Nile, hantavirus, Lyme disease, or malaria (Bai et al., 2013; De Luca and Giraldi, 2011; McMichael et al., 2006; Patz et al., 2014; Ramasamy and Surendran, 2011). All of these climate-related effects would increase personal and social vulnerability, promoting conflict and/or migration (Bronen and Chapin, 2013; Burke et al., 2010; McMichael et al., 2012a; National Research Council, 2013b).

According to Fritze, mental health impacts of climate change will emerge in three distinct ways (Fritze et al., 2008). First, direct effects will occur through personal experience of extreme weather events, as has been observed among victims of various extreme weather events (Amstadter et al., 2009; Bronen and Chapin, 2013; Hart et al., 2011; Larrance et al., 2007; Schmeltz et al., 2013). Second, disruptions in social, economic and environmental determinates of health will exacerbate a variety of mental health conditions (Blashki et al., 2007). Third, individuals may experience emotional distress and anxiety about the future with the realization and understanding of the consequences of, and threats posed by, global warming (Fritze et al., 2008).

While a few geographical areas may see increased agricultural productivity, most experts agree that the overall trend will be towards worsened food insecurity (Lobell and Gourdji, 2012). Shorter winters and higher CO_2 concentrations stimulate photosynthesis, potentially increasing crop yields by as much as 1.8% per decade (Lobell et al., 2011). At the same time, however, warmer temperatures increase plants' need for water, leading to drought and heat-related crop failure. Best current models put the plausible net change in global crop yield between 2% gain and −3% loss per decade, compared to today's productivity (Lobell and Gourdji, 2012). The bigger picture, however, includes not only average global production, but localized effects of droughts, floods, and insect damage. Increasing costs involved with transportation, irrigation, fertilizers and pesticides will reduce local- and regional-level resilience to climatic threats, creating life-threatening crises for the world's more vulnerable populations. The annual number of food emergencies, as defined by the United Nations World Food Program, has risen from 15 per year in the 1980s to 30 per year today (Schneider and Garrett, 2009). Food insecurity already threatens 1 in 7 of earth's population, with more than a billion people acutely or chronically malnourished on any given day. One study published in *Science* projected severe temperature increases in the tropics and sub-tropics, where half of humanity lives, and warned that “human consequences of global climate change could be enormous” (Battisti and Naylor, 2009).

Systems providing clean drinking water and sanitary sewage disposal are among the most important achievements of the industrial revolution, and a major driver of the second phase of Omran's epidemiological transition. Nevertheless, close to a billion people lack access to potable water, and more than 2 billion live without sanitary sewage systems (United Nations and World Health Organization, 2014). While this is clearly an area amenable to improvement regardless of warming-induced climate change, environmental threats to water security are sure to worsen. Some water-stressed regions will become hotter and more arid, decreasing food production, while others will suffer more frequent and consequential flooding, impacting water and sanitation as well as agriculture. Perhaps the most worrisome long term water-related threat comes from loss of mountain glaciers, which feed rivers providing water for more than a sixth of the world's population (Beniston and Stoffel, 2014; Laghari, 2013). Even if average annual rain and snowfall levels remain adequate, seasonal variations will increase, leading to more and worse downpours and flooding, and longer and more threatening dry seasons.

There is continuing uncertainty regarding projected increases in the frequency and severity of extreme weather events. Heat waves, heavy precipitation events, floods, droughts, and windstorms at sea and on land have all increased over the past few decades (Coumou and Rahmstorf, 2012; Diffenbaugh et al., 2013; Lane et al., 2013). However, the inherent variability in the measurement of these events has meant that some of these increases have not yet reached statistical significance. For instance, strong trends in worsening storms have been observed in the North Atlantic and the Indian Oceans (Emanuel, 2005). Heat waves are especially life-threatening, with the 2003 European heat wave responsible for the loss of more than 60,000 lives (Analitis et al., 2013; Filleul et al., 2006; Orru et al., 2013). Heat- and drought-related events will threaten some populations, but others will be faced with floods and freezing, as climate change disrupts moderating influences such as temperate weather patterns and ocean currents.

Substantive questions emerge related to responsibility, ethics and, equity. Clearly, the negative health consequences of climate change will disproportionally harm the world's poor and disadvantaged populations, who have in general contributed the least towards greenhouse gas emissions (Anstey, 2013; Bernstein and Rice, 2013; Bowen and Friel, 2012; Donohoe, 2003; Singh, 2012). For example, expected mortality impacts of environmental change have been projected to be as much as 500 times higher in African than European populations (McMichael et al., 2008). Disadvantaged people suffer first and worst when subjected to new threats, as they already have multiple risks and little margin of safety.

Appropriate response to the threats that climate change presents varies dramatically by locale (Patz and Olson, 2006). Poor, low-lying and under-developed regions are under the greatest threat, but also have the greatest potential cost-effective gain from appropriate action (Bowen and Friel, 2012). Improvements in built infrastructure targeting potable water, sewage, and storm run-off are of high priority, as are investments in sustainable agriculture, housing, transportation and education. Emergency response systems able to alert people and provide safety during extreme weather events are needed, as are new or better sea walls in many coastal locations. Basic health services, including vaccination, maternity and infant care, rehydration, injury prevention and treatment, and infectious disease prevention and treatment will strengthen resilience and facilitate gradual long-term health gains. Long term sustainability in the developing world is crucially dependent on population stabilization (Carlowe, 2009).

The main challenge of the developed world is to vastly reduce greenhouse gas emissions from fossil fuel combustion, and to maintain a productive economy while doing so (National Climate Assessment and Development Advisory Committee, 2014). Climate science tells us that in order to maximize the likelihood of a sustainable future in a livable world, only a small proportion of earth's remaining fossil fuel reserves can be burned for energy. In this light, seeking new coal or oil deposits, or exploiting existing tar sand deposits, does not appear to be compatible with a long-term livable future. Given the high levels of energy consumption that people in the developed world have come to expect, the challenges of rapidly moving to a net-zero carbon economy are formidable, indeed. But this is what it seems that we must do, if we are to leave our descendants with both civilization and planetary ecosystem intact.

Several authors have begun to investigate the potential health benefits of transition to a low-carbon economy (Anon, 2000; Bouzid et al., 2013; Cheng and Berry, 2013; Friel et al., 2011; Haines, 2012; Holmner et al., 2012; McMichael, 2013; Patz and Hahn, 2012). For instance, dramatic reductions in the use of animal-based foods and energy-intensive transportation (eg. personal vehicles, jet travel, elevators, etc.) could lead to substantive reductions in obesity, diabetes and heart disease (Friel et al., 2009; Haines and Dora, 2012). Improvements in urban transportation systems could both reduce greenhouse gases and improve physical fitness, leading to better health (Schmeltz et al., 2013;Woodcock et al., 2009). Reducing the burning of fossil fuels, especially coal, will lower rates of cardiac and respiratory disease and death attributable to air pollution (De et al., 2013; Li et al., 2013; Thurston, 2013). Better insulation and more efficient heating and cooling systems will reduce household energy costs, and savings could be shifted towards health-enhancing activities and products, such as more fruits and vegetables, bicycles and other exercise equipment, and healthy recreational activities (Wilkinson et al., 2009).

Transportation of goods and people requires massive energy expenditure, nearly all of which comes from fossil fuels. Shifting towards more localized economies could substantively reduce humanity's carbon footprint, enhancing both community and personal health. Efforts at reducing carbon footprints should take into account efficiencies. For example, transportation of efficiently produced agricultural products by sea or rail might well leave less of an imprint than trying to produce them locally. Nevertheless, air transport of goods and people will need to be radically reduced if we are to transition to a sustainable carbon neutral economy.

Transmission of electrical energy from source to consumer involves large scale inefficiencies, often involving substantive energy losses. Locally-produced energy based on wind, solar, hydroelectric, geothermal and tidal sources would increase transmission efficiency, provide good jobs, and empower communities to take responsibility for their energy use. Engaging local political, financial, education and health sectors in planning and carrying out energy system transformation could lead to feasible, efficient, and sustainable solutions that national or state level planning might overlook. While it is undoubtedly true that the scale of necessary change will require substantive upfront input, most economic models suggest that investing in preventive efforts now will cost far less than paying for the more expensive consequences later (Cooke, 2013; Haines, 2012; Knowlton et al., 2011; Nemet et al., 2010; Pindyck, in press; Ramanathan and Xu, 2010; Stern, 2013; Stern and Taylor, 2007). It is also true that the projected health co-benefits of reducing fossil fuel use are substantive, and will begin to accrue almost as soon as mitigation efforts are initiated (Cheng and Berry, 2013; Nemet et al., 2010; Roberts, 2009; Thurston, 2013; West et al., 2013).

A few authors have begun to envision the changes that the health care system will need to undertake in response to climate change (Blashki et al., 2007; Ebi, 2011; Parker, 2011; Podein and Hernke, 2010; Richardson et al., 2009; Rosenblatt, 2005; Walker et al., 2011). Several of these have to do with infrastructure and technology. Health care buildings, especially hospitals, are among the most energy-intensive of facilities. Medical interventions, including pharmaceuticals and surgical procedures, depend on highly technical and fossil fuel based energy-intensive infrastructures. Reliance on unnecessary laboratory testing, combined with costly, risky, and marginally effective pharmaceutical intervention, has reached epidemic proportions (Berwick and Hackbarth, 2012; Brody and Light, 2011; Grady and Redberg, 2010; Lenzer, 2012). Overdiagnosis (Gotzsche et al., 2009; Hoffman and Cooper, 2012; Welch et al., 2011) and overtreatment (Abramson, 2004; Brownlee, 2007; Whitaker, 2010) for those that have health insurance may lead to as much harm as lack of access for those that do not (Himmelstein et al., 2001; Lasser et al., 2006). As Ivan Illich warned in 1976 (Illich, 1976), we physicians and our associated biotechnical workforce may have – to some extent – created a “medical nemesis” during the “expropriation of health.” By reducing energy-intensive and low-yield interventions, and by transitioning towards practices aimed at psychosocial as well as physical health, we can support a transition towards a sustainable future. This will involve adopting new paradigms as well as practical solutions, and will require new ways of training health care personnel to deal with new and evolving threats to human health.

Gradually shifting towards more appropriate and effective methods – such as health-enhancing behaviors, nutritional guidance, social support and environmental safety – could integrate well with locally-based and health-promoting agriculture, water, sewage and energy systems. Today, most Americans drive automobiles to get to their doctors. In the future, it might make more sense to use email and telephone for most communications, to have neighborhood-based clinicians available for direct interaction and physical exam when useful, and to reserve analysis of biological specimens and diagnostic imaging for cases where those modalities are proven to be cost-effective (a small fraction of current use, we believe). Delivery of effective public health interventions such as childhood immunization and annual influenza vaccination could be handled by nurses in schools, workplaces, or neighborhood community centers. Health education and promotion, (Patrick et al., 2012) including exercise and nutrition classes, could be led by public community health workers in easily accessed locations. Psychological counseling, social work services and dentistry could also be located at the community or neighborhood level, so that active transport (walking, biking) could replace energy-intensive and polluting transportation as the predominant mode of accessing health care. To some extent, these sorts of things are already available in places such as Denmark, The Netherlands, and Cuba, where positive examples can be learned from, as high cost high impact systems in America and elsewhere seek to reduce their carbon footprints.

Health care systems are composed of numerous individuals, all of whom have the opportunity and perhaps moral obligation to act. Given the gravity of the situation, health professionals have a duty to educate their patients and the public, and use their societal positions to call for policies discussed above. First, interested health professionals should lobby their local medical schools and residency programs to adopt curricula in climate change health impacts, and health-related mitigation and adaptation. Second, doctors, nurses and allied health professionals should actively participate in groups like the European Health and Environment Alliance, the US Climate Health Alliance, and Health Care Without Harm (both US and EU), where they can learn how to educate and motivate institutional leadership and elected officials towards better policies and practices. Third, health professionals should mobilize the power of their provider groups and representative organizations such as the American Medical Association and various European medical societies to put lobbying power behind the climate policy statements that many of these groups have already made. Fourth, and finally, to reach the public's ears, health professionals must work with well-connected environment and climate advocacy groups, such as the Sierra Club, 350.org, and the World Wide Fund for Nature.

For some readers, especially those not yet convinced of the basic findings of climate science, these ideas and proposals may seem difficult to accept, or even to discuss or consider. Nevertheless, the evidence is robust and the basic science is sound, with tremendous consensus among those who have studied it (Cook et al., 2013; IPCC Working Group 2, 2014; Patz et al., 2014). For those that do not accept the scientific consensus, perhaps the health co-benefits expected to come from transitioning towards a carbon-neutral economy will be enough to gain acceptance, if not active support. For those whose minds are open to scientific findings, and are able to understand and accept the enormity of the climate-related challenges facing humanity, this essay may make more sense, and will hopefully stimulate thought and conversation to move us forward. As Costello reminds us, neither attitudes of climate change denial nor catastrophic fatalism should be used to guide societal-level decision making (Costello et al., 2011). Instead, we need to take a hard look at what the best science is telling us, and then work towards pragmatic approaches to maximize benefits and minimize harms.

Which brings us back to Omran's “epidemiological transition,” a foundational theory these past few decades (Defo, 2014; Feinleib, 2008; Riley and Alter, 1989; Szreter, 2004). Taking a broad view of human history, it is clear that the forces shaping such basic parameters as fertility, mortality and life-expectancy are complex, changing, and influenced by a number of factors, including structural influences resulting from large-scale human activities. Human health – mental and physical, symptomatic and functional – is influenced by complex underlying phenomena inextricably linked to the world in which we live. Over several centuries, unprecedented technological change has facilitated revolutions in agriculture, potable water and sewage, public health and medical care that have allowed tremendous increases in life-expectancy and population growth. Until recently, widespread belief in the power of technology and economic productivity to improve human lives has yielded a false promise that our collective future was assured. Until recently, the physical and biological nature of that world was understood to be relatively constant, with the assumption that our actions could not markedly influence the habitability of the planet as a whole. But now we know better. Widespread burning of fossil fuels, combined with the destruction of forests, has already influenced earth's temperature, sea level, and climate, and is threatening to wreak havoc on an unprecedented scale. Our ability to keep average global warming to the 2 °C considered safe by our planet's most knowledgeable scientists may be the major determinant of whether Omran's “Age of Degenerative and Man-Made Diseases”will continue, or whether we will be entering an age of civilization collapse and population decline, as resource-depleted and socially-stressed societies fail to adapt to a heat-stressed planet with new coastlines, unpredictable water resources and agricultural capacity, and a small fraction of the biodiversity that a billion years of evolution has provided.

Acknowledgments

We would like to thank our colleagues in the University of Wisconsin, School of Medicine and Public Health, and our home Department of Family Medicine, and especially Mary Checovich for copy-editing, formatting, and diligently assisting with the submission and review process. We would also like to acknowledge the thousands of scientists across the globe who have worked tirelessly to understand the nature and impact of anthropogenic global warming and climate change. Finally, we would like to dedicate this paper to Jeff Patterson DO, physician, teacher, humanitarian, and Physicians for Social Responsibility leader and activist, who died unexpectedly earlier this year. Bruce Barrett is supported by a Midcareer Investigator Award in Patient-Oriented Research (K24AT006543) from the National Centers of Complementary and Alternative Medicine at the National Institutes of Health.

References

Abramson J. Overdosed America: The Broken Promise of American Medicine. Harper Perennial. 2004

Amstadter AB, Acierno R, Richardson LK, Kilpatrick DG, Gros DF, Gaboury MT, et al. Posttyphoon prevalence of posttraumatic stress disorder, major depressive disorder, panic disorder, and generalized anxiety disorder in a Vietnamese sample. J. Trauma. Stress. 2009 Jun; 22(3):180–188. [PubMed: 19455707]

Analitis A, Michelozzi P, D'Ippoliti D, De'donato F, Menne B, Matthies F, et al. Effects of heat waves on mortality: effect modification and confounding by air pollutants. Epidemiology. 2013 Oct.24

Investment of health insurers and mutual funds in tobacco stocks. JAMA. Aug 9.284(6):697.

Anstey MH. Climate change and health — what's the problem? Glob. Health. 2013; 9(1):4.

Bai L, Morton LC, Liu Q. Climate change and mosquito-borne diseases in China: a review. Glob. Health. 2013; 9:10.

Bates, BC.; Kundzewicz, ZW.; Wu, S.; Palutikof, JP. IPCC Secretariat. Geneva: 2008. Climate change and water. Technical Paper of the Intergovernmental Panel on Climate Change.

Battisti DS, Naylor RL. Historical warnings of future food insecurity with unprecedented seasonal heat. Science. 2009; 323:240–244. [PubMed: 19131626]

NIH-PA Author Manuscript

NIH-PA Author Manuscript

Beniston M, Stoffel M. Assessing the impacts of climatic change on mountain water resources. Sci. Total Environ. 2014 Sep 15.493:1129–1137. [PubMed: 24360916]

Benton GS. Carbon dioxide and its role in climate change. Proc. Natl. Acad. Sci. U. S. A. 1970 Oct; 67(2):898–899. [PubMed: 5289026]

Bernstein AS, Rice MB. Lungs in a warming world: climate change and respiratory health. Chest. 2013 May; 143(5):1455–1459. [PubMed: 23648909]

Berwick DM, Hackbarth AD. Eliminating waste in US health care. JAMA. 2012 Apr 11; 307(14): 1513–1516. [PubMed: 22419800]

Blashki G, McMichael T, Karoly DJ. Climate change and primary health care. Aust. Fam. Physician. 2007 Dec; 36(12):986–989. [PubMed: 18075618]

Bordenave G. Louis Pasteur (1822–1895). Microbes Infect. 2003 May; 5(6):553–560. [PubMed: 12758285]

Bouzid M, Hooper L, Hunter PR. The effectiveness of public health interventions to reduce the health impact of climate change: a systematic review of systematic reviews. PLoS ONE. 2013; 8(4):e62041. [PubMed: 23634220]

Bowen KJ, Friel S. Climate change adaptation: where does global health fit in the agenda? Glob. Health. 2012; 8:10.

Brody H, Light DW. The inverse benefit law: how drug marketing undermines patient safety and public health. Am. J. Public Health. 2011 Mar; 101(3):399–404. [PubMed: 21233426]

Bronen R, Chapin FS III. Adaptive governance and institutional strategies for climate-induced community relocations in Alaska. Proc. Natl. Acad. Sci. U. S. A. 2013 Jun 4; 110(23):9320–9325. [PubMed: 23690592]

Brownlee, S. Overtreated: Why Too Much Medicine is Making Us Sicker and Poorer. Bloomsbury: 2007.

Burke MB, Miguel E, Satyanath S, Dykema JA, Lobell DB. Climate robustly linked to African civil war. Proc. Natl. Acad. Sci. U. S. A. 2010 Dec 21; 107(51):E185–E187. [PubMed: 21118990]

Cardinale BJ, Duffy JE, Gonzalez A, Hooper DU, Perrings C, Venail P, et al. Biodiversity loss and its impact on humanity. Nature. 2012 Jun 7; 486(7401):59–67. [PubMed: 22678280]

Carlowe J. Success of climate change control depends on access to reproductive health care. BMJ. 2009; 339:b4834. [PubMed: 19923154]

Cheng JJ, Berry P. Health co-benefits and risks of public health adaptation strategies to climate change: a review of current literature. Int. J. Public Health. 2013 Apr; 58(2):305–311. [PubMed: 23111371]

Cook J, Nuccitelli D, Green SA, Richardson M, Winkler B, Painting R, et al. Quantifying the consensus on anthropogenic global warming in the scientific literature. Environ. Res. Lett. 2013; 8:1–7.

Cooke RM. Model uncertainty in economic impacts of climate change: Bernoulli versus Lotka Volterra dynamics. Integr. Environ. Assess. Manag. 2013 Jan; 9(1):2–6. [PubMed: 22544625]

Costello A, Abbas M, Allen A, Ball S, Bell S, Bellamy R, et al. Managing the health effects of climate change: Lancet and University College London Institute for Global Health Commission. Lancet. 2009 May 16; 373(9676):1693–1733. [PubMed: 19447250]

Costello A, Maslin M, Montgomery H, Johnson AM, Ekins P. Global health and climate change: moving from denial and catastrophic fatalism to positive action. Philos. Trans. A Math. Phys. Eng. Sci. 2011 May 13; 369(1942):1866–1882. [PubMed: 21464077]

Coumou D, Rahmstorf S. A decade of weather extremes. Nat. Clim. Chang. 2012 Jul; 2(7):491–496.

De Luca D'A, Giraldi G. A world wide public health problem: the principal reemerging infectious diseases. Clin. Ter. 2011 May; 162(3):e93–e98. [PubMed: 21717041]

De SM, Katsouyanni K, Michelozzi P. Climate change, extreme weather events, air pollution and respiratory health in Europe. Eur. Respir. J. 2013 Sep; 42(3):826–843. [PubMed: 23314896]

Defo BK. Epidemiological Transitions — Beyond Omran's Theory. Glob. Health Action (Special Issue). 2014

Diffenbaugh NS, Scherer M, Trapp RJ. Robust increases in severe thunderstorm environments in response to greenhouse forcing. Proc. Natl. Acad. Sci. U. S. A. 2013 Sep.23

Donohoe M. Causes and health consequences of environmental degradation and social injustice. Soc. Sci. Med. 2003 Feb; 56(3):573–587. [PubMed: 12570975]

Ebi K. Climate change and health risks: assessing and responding to them through 'adaptive management'. Health Aff. (Millwood). 2011 May; 30(5):924–930. [PubMed: 21555476]

Ehrlich, PR. The Population Bomb. New York: Ballantine Books; 1968.

Emanuel K. Increasing destructiveness of tropical cyclones over the past 30 years. Nature. 2005; 436:686–688. [PubMed: 16056221]

Feinleib M. The epidemiologic transition model: accomplishments and challenges. Ann. Epidemiol. 2008 Nov; 18(11):865–867. [PubMed: 18823792]

Filleul L, Cassadou S, Medina S, Fabres P, Lefranc A, Eilstein D, et al. The relation between temperature, ozone, and mortality in nine French cities during the heat wave of 2003. Environ. Health Perspect. 2006 Sep; 114(9):1344–1347. [PubMed: 16966086]

Folger T. Rising seas. Natl. Geogr. 2013; 224(3):30–59.

Friel S, Dangour AD, Garnett T, Lock K, Chalabi Z, Roberts I, et al. Public health benefits of strategies to reduce greenhouse-gas emissions: food and agriculture. Lancet. 2009 Dec 12; 374(9706):2016–2025. [PubMed: 19942280]

Friel S, Hancock T, Kjellstrom T, McGranahan G, Monge P, Roy J. Urban health inequities and the added pressure of climate change: an action-oriented research agenda. J. Urban Health. 2011 Oct; 88(5):886–895. [PubMed: 21861210]

Fritze JG, Blashki GA, Burke S, Wiseman J. Hope, despair and transformation: climate change and the promotion of mental health and wellbeing. Int. J. Ment. Health Syst. 2008; 2(1):13. [PubMed: 18799005]

Gast PF. Climate change. Science. 1971 Sep 10; 173(4001):982–983. [PubMed: 17796569]

Gotzsche PC, Jorgensen KJ, Maehlen J, Zahl PH. Estimation of lead time and overdiagnosis in breast cancer screening. Br. J. Cancer. 2009 Jan 13.100(1):219. [PubMed: 19127274]

Grady D, Redberg RF. Less is more: how less health care can result in better health. Arch. Intern. Med. 2010 May 10; 170(9):749–750. [PubMed: 20458080]

Haines A. Sustainable policies to improve health and prevent climate change. Soc. Sci. Med. 2012 Mar; 74(5):680–683. [PubMed: 22197291]

Haines A, Dora C. How the low carbon economy can improve health. BMJ. 2012; 344:e1018. [PubMed: 22431656]

Hansen J, Sato M, Russell G, Kharecha P. Climate sensitivity, sea level and atmospheric carbon dioxide. Philos. Trans. A Math. Phys. Eng. Sci. 2013 Oct 28.371(2001):20120294. [PubMed: 24043864]

Hart CR, Berry HL, Tonna AM. Improving the mental health of rural New South Wales communities facing drought and other adversities. Aust. J. Rural Health. 2011 Oct; 19(5):231–238. [PubMed: 21933364]

Himmelstein, DU.; Woolhandler, S.; Hellander, I. Bleeding the Patient: The Consequences of Corporate Health Care. Philadelphia: Common Courage Press; 2001.

Hoffman JR, Cooper RJ. Overdiagnosis of disease: a modern epidemic. Arch. Intern. Med. 2012 Jun. 25:1–2.

Holmner A, Rocklov J, Ng N, Nilsson M. Climate change and eHealth: a promising strategy for health sector mitigation and adaptation. Glob. Health Action. 2012; 5

Honda Y, Kondo M, McGregor G, Kim H, Guo YL, Hijioka Y, et al. Heat-related mortality risk model for climate change impact projection. Environ. Health Prev. Med. 2014 Aug 9; 19(1):56–63. [PubMed: 23928946]

Hooper DU, Adair EC, Cardinale BJ, Byrnes JE, Hungate BA, Matulich KL, et al. A global synthesis reveals biodiversity loss as a major driver of ecosystem change. Nature. 2012 Jun 7; 486(7401): 105–108. [PubMed: 22678289]

Illich, I. Medical Nemesis: The Expropriation of Health. New York: Pantheon Books; 1976.

Intergovernmental Panel on Climate Change. Climate Change 2007: Impacts, Adaptation and Vulnerability. Cambridge University Press; 2007.

IPCC Working Group 1. Summary for policy makers. Intergovernmental panel on climate change. Report No.: Twelfth Session Report. 2013 Sep 27.

Climate Change 2014. Summary for policymakers. Intergovernmental panel on climate change. Report No.: Twelfth Session Report, Released September. 2013 Sep 27.27:2013.

IPCC Working Group 2. Climate Change 2014: Impacts, Adaptation, and Vulnerability. 2014 Mar 31.

Joughin I, Smith BE, Medley B. Marine ice sheet collapse potentially under way for the Thwaites Glacier Basin, West Antarctica. Science. 2014 May 16; 344(6185):735–738. [PubMed: 24821948]

Knowlton K, Rotkin-Ellman M, Geballe L, Max W, Solomon GM. Six climate change-related events in the United States accounted for about $14 billion in lost lives and health costs. Health Aff. (Millwood). 2011 Nov; 30(11):2167–2176. [PubMed: 22068410]

Koch T, Denike K. Crediting his critics' concerns: remaking John Snow's map of Broad Street cholera, 1854. Soc. Sci. Med. 2009 Oct; 69(8):1246–1251. [PubMed: 19716638]

Kravchenko J, Abernethy AP, Fawzy M, Lyerly HK. Minimization of heatwave morbidity and mortality. Am. J. Prev. Med. 2013 Mar; 44(3):274–282. [PubMed: 23415125]

Laghari JR. Climate change: melting glaciers bring energy uncertainty. Nature. 2013 Oct 31; 502(7473):617–618. [PubMed: 24180016]

Lane K, Charles-Guzman K, Wheeler K, Abid Z, Graber N, Matte T. Health effects of coastal storms and flooding in urban areas: a review and vulnerability assessment. J. Environ. Public Health. 2013; 2013:913064. [PubMed: 23818911]

Larrance R, Anastario M, Lawry L. Health status among internally displaced persons in Louisiana and Mississippi travel trailer parks. Ann. Emerg. Med. 2007 May; 49(5):590–601. 601. [PubMed: 17397967]

Lasser KE, Himmelstein DU, Woolhandler S. Access to care, health status, and health disparities in the United States and Canada: results of a cross-national population-based survey. Am. J. Public Health. 2006 Jul; 96(7):1300–1307. [PubMed: 16735628]

Lenzer J. Unnecessary care: are doctors in denial and is profit driven healthcare to blame? BMJ. 2012; 345:e6230. [PubMed: 23033411]

Li P, Xin J, Wang Y, Wang S, Li G, Pan X, et al. The acute effects of fine particles on respiratory mortality and morbidity in Beijing, 2004–2009. Environ. Sci. Pollut. Res. Int. 2013 Sep; 20(9): 6433–6444. [PubMed: 23589266]

Lobell DB, Gourdji SM. The influence of climate change on global crop productivity. Plant Physiol. 2012 Dec; 160(4):1686–1697. [PubMed: 23054565]

Lobell DB, Burke MB, Tebaldi C, Mastrandrea MD, Falcon WP, Naylor RL. Prioritizing climate change adaptation needs for food security in 2030. Science. 2008 Feb 1; 319(5863):607–610. [PubMed: 18239122]

Lobell DB, Schlenker W, Costa-Roberts J. Climate trends and global crop production since 1980. Science. 2011 Jul 29; 333(6042):616–620. [PubMed: 21551030]

MacArthur, R.; Wilson, EO. The Theory of Island Biogeography. Princeton University Press; 1967.

Malthus TR. An essay on the principle of population. 1798 Quoted in: http://en.wikipedia.org/wiki/Thomas_Robert_Malthus:OxfordWorld'sClassicsreprint.

Manabe S, Wetherald RT. The effects of doubling the CO2 concentration on the climate of a general circulation model. J. Atmos. Sci. 1975; 32(3):3–15.

Mayhew PJ, Jenkins GB, Benton TG. A long-term association between global temperature and biodiversity, origination and extinction in the fossil record. Proc. Biol. Sci. 2008 Jan 7; 275(1630): 47–53. [PubMed: 17956842]

McMichael AJ. Globalization, climate change, and human health. N. Engl. J. Med. 2013 Apr 4; 368(14):1335–1343. [PubMed: 23550671]

McMichael AJ, Woodruff RE, Hales S. Climate change and human health: present and future risks. Lancet. 2006 Mar 11; 367(9513):859–869. [PubMed: 16530580]

McMichael AJ, Friel S, Nyong A, Corvalan C. Global environmental change and health: impacts, inequalities and the health sector. BMJ. 2008; 336:191–194. [PubMed: 18219041]

McMichael C, Barnett J, McMichael AJ. An ill wind? Climate change, migration, and health. Environ. Health Perspect. 2012a May; 120(5):646–654. [PubMed: 22266739]

McMichael T, Montgomery H, Costello A. Health risks, present and future, from global climate change. BMJ. 2012b; 344:e1359. [PubMed: 22431661]

Meadows, DH.; Meadows, DL.; Randers, J.; Behrens, WW. The Limits to Growth. Universe Books; 1972.

Meinshausen M, Meinshausen N, Hare W, Raper SC, Frieler K, Knutti R, et al. Greenhouse-gas emission targets for limiting global warming to 2 degrees C. Nature. 2009 Apr 30; 458(7242): 1158–1162. [PubMed: 19407799]

Murray NE, Quam MB, Wilder-Smith A. Epidemiology of dengue: past, present and future prospects. Clin. Epidemiol. 2013; 5:299–309. [PubMed: 23990732]

National Academy of Sciences. Climate Change: Evidence and Causes. 2014

National Climate Assessment and Development Advisory Committee. U.S. Global Change Research Program. 2014. http://www.globalchange.gov/ncadac.

National Research Council. Abrupt Impacts of Climate Change: Anticipating Surprises. National Academies of Science. 2013a

National Research Council. Climate and Social Stress: Implications for Security Analysis. National Academies Press; 2013b.

Nemet GF, Holloway T, Meier P. Implications of incorporating air-quality co-benefits into climate change policymaking. Environ. Res. Lett. 2010; 5(1):1–9.

Omran AR. The epidemiologic transition: a theory of the epidemiology of population change. Milbank Q. 1971; 49(4):509–538.

Orru H, Andersson C, Ebi KL, Langner J, Astrom C, Forsberg B. Impact of climate change on ozone-related mortality and morbidity in Europe. Eur. Respir. J. 2013 Feb; 41(2):285–294. [PubMed: 22743679]

Paneth N. Assessing the contributions of John Snow to epidemiology: 150 years after removal of the broad street pump handle. Epidemiology. 2004 Sep; 15(5):514–516. [PubMed: 15308944]

Parker CL. Slowing global warming: benefits for patients and the planet. Am. Fam. Physician. 2011 Aug 1; 84(3):271–278. [PubMed: 21842773]

Patrick R, Capetola T, Townsend M, Nuttman S. Health promotion and climate change: exploring the core competencies required for action. Health Promot. Int. 2012 Dec; 27(4):475–485. [PubMed: 21914637]

Patz JA, Hahn MB. Climate change and human health: A one health approach. Curr. Top. Microbiol. Immunol. 2012 Nov.18

Patz JA, Olson SH. Climate change and health: global to local influences on disease risk. Ann. Trop. Med. Parasitol. 2006 Jul; 100(5–6):535–549. [PubMed: 16899153]

Patz JA, Reisen WK. Immunology, climate change and vector-borne diseases. Trends Immunol. 2001 Apr; 22(4):171–172. [PubMed: 11274908]

Patz JA, Gibbs H, Foley J, Rogers J, Smith K. Climate change and global health: quantifying a growing ethical crisis. EcoHealth. 2007; 4:397–405.

Patz JA, Frumkin H, Holloway T, Vimont DJ, Haines A. Climate change: challenges and opportunities for global health. JAMA. 2014 Sep.22

Pianka ER. On r and k selection. Am. Nat. 1970; 104(940):592–597.

Pimm SL, Jenkins CN, Abell R, Brooks TM, Gittleman JL, Joppa LN, et al. The biodiversity of species and their rates of extinction, distribution, and protection. Science. 2014 May 30.344(6187):1246752. [PubMed: 24876501]

Pindyck RS. Climate change policy: what do the models tell us. J. Econ. Lit. 2013; 51(3):860–872.

Podein RJ, Hernke MT. Integrating sustainability and health care. Prim. Care. 2010 Mar; 37(1):137–147. [PubMed: 20189003]

Rahmstorf S. A new view on sea level rise. Has the IPCC underestimated the risk of sea level rise. Nat. Rep. Climate Change. 2010; 4

Ramanathan V, Xu Y. The Copenhagen accord for limiting global warming: criteria, constraints, and available avenues. Proc. Natl. Acad. Sci. U. S. A. 2010 May 4; 107(18):8055–8062. [PubMed: 20439712]

Ramasamy R, Surendran SN. Possible impact of rising sea levels on vector-borne infectious diseases. BMC Infect. Dis. 2011; 11:18. [PubMed: 21241521]

Rapley C. The health impacts of climate change. BMJ. 2012; 344:e1026. [PubMed: 22431657]

Richardson J, Kagawa F, Nichols A. Health, energy vulnerability and climate change: a retrospective thematic analysis of primary care trust policies and practices. Public Health. 2009 Dec; 123(12): 765–770. [PubMed: 19944436]

Rignot E, Mouginot J, Morlighem M, Seroussi H, Scheuchl B. Widespread, rapid grounding line retreat of Pine Island, Thwaites, Smith, and Kohler glaciers, West Antarctica, from 1992 to 2011. Geophys. Res. Lett. 2014; 41 http://dx.doi.org/10.1002/2014GL060140.

Riley JC, Alter G. The epidemiologic transition and morbidity. Ann. Demogr. Hist. 1989:199–213. (Paris).

Roberts I. The health co-benefits of climate change policies: doctors have a responsibility to future generations. Clin. Med. 2009 Jun; 9(3):212–213. [PubMed: 19634380]

Rosenblatt RA. Ecological change and the future of the human species: can physicians make a difference? Ann. Fam. Med. 2005 Mar; 3(2):173–176. [PubMed: 15798046]

Sauerborn R, Ebi K. Climate change and natural disasters: integrating science and practice to protect health. Glob. Health Action. 2012; 5:1–7.

Schmeltz MT, Gonzalez SK, Fuentes L, Kwan A, Ortega-Williams A, Cowan LP. Lessons from hurricane Sandy: a community response in Brooklyn, New York. J. Urban Health. 2013 Oct; 90(5):799–809. [PubMed: 24022182]

Schneider K, Garrett L. The end of the era of generosity? Global health amid economic crisis. Philos. Ethics Humanit. Med. 2009; 4:1. [PubMed: 19134211]

Singh JA. Why human health and health ethics must be central to climate change deliberations. PLoS Med. 2012; 9(6):e1001229. [PubMed: 22679396]

Stanke C, Kerac M, Prudhomme C, Medlock J, Murray V. Health effects of drought: a systematic review of the evidence. PLoS Curr. 2013; 5

Stern N. The structure of economic modeling of the potential impacts of climate change: grafting gross underestimation of risk onto already narrow science models. J. Econ. Lit. 2013; 51(3):838–859.

Stern N, Taylor C. Economics. Climate change: risk, ethics, and the Stern review. Science. 2007 Jul 13; 317(5835):203–204. [PubMed: 17626870]

Szreter S. The population health approach in historical perspective. Am. J. Public Health. 2003 Mar; 93(3):421–431. [PubMed: 12604486]

Szreter S. Industrialization and health. Br. Med. Bull. 2004; 69:75–86. [PubMed: 15226198]

Thurston GD. Health co-benefits. Nat. Clim. Chang. 2013; 3:863–864.

Tulchinsky TH. It is not just the broad street pump. J. Public Health (Oxf.). 2010 Mar; 32(1):134–135. [PubMed: 19959494]

United Nations, World Health Organization. Drinking Water, Sanitation and Hygiene. 2014.

Walker R, Hassall J, Chaplin S, Congues J, Bajayo R, Mason W. Health promotion interventions to address climate change using a primary health care approach: a literature review. Health Promot. J. Austr. 2011 Dec.22:S6–S12. Spec No. [PubMed: 22518912]

Welch, G.; Schwartz, LM.; Woloshin, S. Over diagnosed: Making Us Sicker in the Pursuit of Health. Beacon Press; 2011.

West JJ, Smith SJ, Silva RA, et al. Co-benefits of mitigating global greenhouse gas emissions for future air quality and human health. Nat. Clim. Chang. 2013; 3:885–889. [PubMed: 24926321]

Whitaker R. Anatomy of an Epidemic: Magic Bullets, Psychiatric Drugs, and the Astonishing Rise of Mental Illness in America. Random House, Crown. 2010

Wilkinson P, Smith KR, Davies M, Adair H, Armstrong BG, Barrett M, et al. Public health benefits of strategies to reduce greenhouse-gas emissions: household energy. Lancet. 2009 Dec 5; 374(9705):1917–1929. [PubMed: 19942273]

Woodcock J, Edwards P, Tonne C, Armstrong BG, Ashiru O, Banister D, et al. Public health benefits of strategies to reduce greenhouse-gas emissions: urban land transport. Lancet. 2009 Dec 5; 374(9705):1930–1943. [PubMed: 19942277]

Woodward M, Kapelan Z, Gouldby B. Adaptive flood risk management under climate change uncertainty using real options and optimization. Risk Anal. 2013 Jul 8; 34(1):75–92.

World Resources Institute. Millenium Ecosystem Assessment: Ecosystems and Human Well-Being Biodiversity Synthesis. Washington DC: World Resources Institute; 2005.