



# Human Health in an Era of Global Environmental Change

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# Executive Summary

The aim of this reference paper is to provide an overview of the relationship between global environmental change and human health – the health of current and future generations. It draws on the 2015 report *Safeguarding Human Health in the Anthropocene Epoch: Report of The Rockefeller Foundation–Lancet Commission on Planetary Health*, and on other key papers published since then, to introduce key concepts in planetary health. The paper cautions against the continued damage to the natural resource base on which good health depends.

Exactly how the environment impacts human health is complicated, however, particularly at the global level, due to the long timescales involved and the challenge of isolating environmental impact from the many other variables at play. Human life expectancy has nearly doubled over the past 200 years in most developed countries, mainly due to a safer and more stable food supply, improved sanitation and clean water supplies, and improved public health in cities. Medical advances have also played an important part, particularly in the form of antibiotics and vaccines. Human health has nevertheless been impacted by pollution and global environmental degradation.

The principle trends borne out by this work include the following:

- Human health has made tremendous strides over the course of the last century. Life expectancy has risen from 30–40 years prior to the 19th century to more than 80 years in some parts of the world today. Average global average life expectancy at birth stood at 71.4 years in 2015. Infant mortality has also declined dramatically. Progress has nevertheless been uneven around the globe, with some portions of the developing world continuing to experience severely poor health, with average life expectancy of around 50 years.
- There is a strong positive correlation between life expectancy and increased GDP per capita and an even stronger correlation with health spending per capita. Monaco, which has the world's highest per capita income, also has the world's highest life expectancy of almost 90 years. Sierra Leone, which has the world's lowest life expectancy at only 50, is also one of the world's poorest countries.
- In addition to income growth, and perhaps also an outcome of that growth, human health has benefitted from the advent of modern agriculture and of a safer and more stable food supply. This development has been accompanied by the rise of cities with strong public health measures and greater access to medical care, and the introduction of electricity to power heating, refrigerators, air conditioners and many other appliances that improve health and well-being. While urbanization in pre-industrial times often brought about ill-health through overcrowding and unsanitary conditions, leading to the coining of the term “urban penalty,” advances in public health have now transformed this phenomenon into an “urban advantage.” People living in cities generally enjoy better health than people in surrounding rural areas.
- The world is undergoing two major and concurrent transitions that must be studied carefully to understand the evolution of human health: The Demographic and Epidemiological Transitions. The Demographic Transition sees fewer deaths at birth, lower birthrates and more people surviving to old age: it has reached some of its highest stages in Europe, Japan and the USA, but remains in its lowest stages in some developing countries, particularly in sub-Saharan Africa.

- The Epidemiological Transition follows closely from the demographic and has allowed the developed world to transition from infectious or communicable diseases as a primary cause of mortality, into an era of non-communicable diseases (NCDs). Countries that are at the bottom of the Demographic Transition are also the ones at the bottom of Epidemiological one. The transitions stand as a testimony of human progress. However, in many parts of the developing world, the fundamentals of a basic public health agenda remain unmet and the transitions continue to be in their early phases.
- The world has now entered an era of NCDs. According to the Global Burden of Disease, in 2015, 70% of all 56.5 million deaths worldwide – 40 million – were due to NCDs. In order of disease burden these include cardiovascular disease, cancer, chronic respiratory disease, and diabetes. The rise in NCDs is primarily attributable to old age, but is also linked to living longer lives in environments where there is increased risk of exposure to contributing factors such as pollution, inactive lifestyles and poor dietary choices.
- While progress in human health has been very significant in recent decades, pollution and other environmental factors, such as poor sanitation and dangerous working conditions, take a significant toll on health. According to the World Health Organization, 23% of all deaths worldwide are attributable to preventable environmental factors, with 16% of all deaths attributable to pollution.
- Global environmental change is closely associated with the forces of the Great Acceleration – the profound transformation in the relationship between humans and the natural world over recent decades. This acceleration has influenced all components of the global environment: the oceans, atmosphere, and land. There is increasing evidence that global environmental change can harm human health through a variety of direct and indirect pathways leading from these accelerations. This needs to be addressed urgently.
- Air pollution stands out in terms of its impact on health. In developing countries, surveillance by the World Health Organization suggests that 98% of urban areas fail to meet WHO air quality guidelines. The figure is close to 50% on average in high-income urban centers.
- The air pollution and climate agendas are intimately linked, with both air pollution and greenhouse gas emissions arising largely from energy use. However, air quality is improving in some developing countries, even as greenhouse gas emissions increase, linked to strong environmental protection regulation.
- Climate change and rising temperatures are likely to increase mortality in certain parts of the globe (though may decrease it in others as colder regions experience less extreme winters). Extreme weather contributes to food insecurity due to crop failure and the increased spread of diseases. The UNEP Emissions Gap Report suggests that we are on course for around a 3° Celsius warming above pre-industrial levels by the end of the 21st century, even if the commitments of the Paris Climate Accord are met.

- By the middle of the 21st century, as many as 1.4 billion people could be affected by sea level rise in coastal zones due to increasing global temperatures, while other areas of the world will face severe water shortages. Per capita freshwater availability has declined by 75% in the Arab world over recent decades, which significantly threatens food security. Heat-related excess mortality of more than 15% is predicted towards the end of the 21st century in Southern Europe, South America and South-East Asia under the highest emission scenarios.
- Combined with intensive agriculture, climate change could reduce the nutritional content of the human diet. Dietary diversity has already declined by 68% between 1961 and 2009 across the globe. More than half a million global annual deaths due to the impacts of climate change on crop yields have been projected by the middle of the 21st century. Biodiversity loss, ocean acidification and the many other forces of global environmental change could also prove seriously harmful to human health.

In sum, while rising incomes and a variety of other factors have led to substantial progress in human health, this progress has been uneven across the globe. If pollution and global environmental change are not seriously tackled, the health of future generations could be undermined.

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## Key to symbols



Air pollution



Water contamination



Chemical pollution



Radiation



Community noise



Occupational risks



Intensive agriculture



Built environments



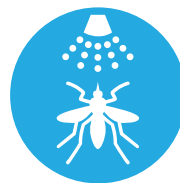
Climate change



Heat stress



Biodiversity loss



Pesticide use



Antimicrobial  
resistance



Active travel



Traffic pollution

# How the environment impacts our health



Figure 1: Environmental change impacts at the local, regional and global level across national and transnational borders. Air pollution from cities drives ocean acidification, for example, and agricultural pollution impacts on water systems in neighbouring countries. The complex, interconnected drivers and impacts need to be better understood and costed.

# 1.0 Human Health in an Era of Global Environmental Change

## 1.1 Introduction

We as humans are not separate from the environment in which we live. We are integrated with it through the air we breathe, the water we drink, and the food we eat. Even within ourselves, we are a complex biological system.<sup>1</sup> Many of the cells within the human body come from bacteria, viruses or other micro-organisms with which we co-exist, and which help or hinder our interaction with the wider, external ecological system.<sup>2</sup> Bacteria in our gut support digestion and influence our response to micro-organisms that can cause disease. This means, as Howard Frumkin\* has attested, “Our health is directly dependent on the proper functioning and diversity of the [Earth’s] biosphere.”

This proper functioning is now under severe stress<sup>3</sup>. Since the beginnings of agriculture and the emergence of the first cities around 10,000 BCE, humans have altered the environment to benefit our own species without due consideration for the impact this has on others. We have removed finite resources such as iron, coal, oil, and gas.<sup>4,5</sup> We have polluted air, water, and land, and have depleted potentially sustainable resources such as forests, soil micronutrients, and marine life at rates that nature cannot replace. The impact of this on the environment is well documented.<sup>6,7</sup> The way in which human health is changing, thanks to advances in sanitation and medical science, is also well understood – smallpox has been eradicated completely<sup>8</sup>, rubella has been eradicated from the Americas, and we are on the brink of seeing global success in polio eradication.<sup>9</sup> Infectious disease is no longer a major killer in the developed world. But as infection becomes less of a risk, rates of heart disease and cancer are rising.

Exactly how the environment impacts human health is complicated, particularly at the global level. We are living longer: human life expectancy has risen from 30–40 years before the 19th century to more than 80 years in some parts of the world today, with a global average life expectancy at birth of 71.4 years in 2015<sup>10</sup>. In this respect, the Earth of the 21st century is a healthier environment for humans than it was in the past. In the 19th century, only 50% of children survived to their fifth birthday, whereas in most developed countries today, child mortality is a fraction of 1%. Between 1 in 100 and 1 in 200 births resulted in the mother’s death, compared with just 2–3 in every 100,000 in some countries today. This is not only related to the condition of the environments in which we live however: medical science also plays an important part. Many previously fatal conditions, such as cancer, diabetes and HIV infection can now be managed with medical care, allowing us to become complacent about the degradation of the natural environment. Progress and development provide clean water and sanitation to urban populations, wiping away diarrhoeal disease and infection, while also polluting that same population’s air through uncontrolled vehicle emissions and industrial chemicals.

Reports such as *Safeguarding Human Health in the Anthropocene Epoch: Report of The Rockefeller Foundation–Lancet Commission on Planetary Health*,<sup>11,12</sup> The Global Burden of Disease (GBD) Study<sup>13</sup>, and the World Health Organization’s *Preventing Disease Through Unhealthy Environments*<sup>14</sup> estimate that as many as 12.6 million deaths globally – 23% of deaths worldwide – are attributable to environmental factors that can be eliminated or avoided. Out of 133 diseases or injuries considered in GBD, 101 have significant links with the environment.<sup>15</sup>

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\* Professor of Environmental and Occupational Health Services at Washington University School of Public Health, speaking at the Inaugural Planetary Health/Geohealth Annual Meeting in Boston, USA, in April 2017.

Scientific and medical progress have given us the ability to off-set ill-health with treatment – for those who can afford it. There are vast disparities in health between different countries, tied closely to their level of economic development, in life expectancy at birth, and the incidence and type of ill-health that impacts their populations.<sup>16</sup> Such disparities are even apparent within countries, based on socio-economic status, ethnic group and gender.<sup>17</sup> Exposure to environmental risk factors such as air pollution and contaminated water supply is often much higher in low- and middle-income countries than in high-income ones.

**As scientific and medical progress has gone hand-in-hand with our  
degradation of the natural environment, human life expectancy has risen  
with our ability to off-set ill-health with treatment.**

For environmentalists, public health experts and economists to move forward, a strong understanding is required of the relationship between human health and the environment, how it has changed over time, and how it is likely to change in future. This paper aims to provide a starting point towards that end, beginning with a brief examination of two key trends:

**Demographic transition** – From high numbers of births with many people dying in early childhood and few surviving to old age, to low numbers of births with most of the population surviving to old age.

**Epidemiological transition** – From most deaths being caused by infection, malnutrition, and complications during childbirth, which can be addressed by medical treatment, to most deaths being caused by non-communicable diseases such as cancer and heart disease, which can be linked to living long lives in unhealthy environments.

## 1.2 The Great Acceleration

Global environmental change is closely associated with the forces of the Great Acceleration<sup>18</sup> – a term coined by Professor Will Steffen to capture the profound transformation in the relationship between humans and the natural world over the previous 60 years. This acceleration has influenced all components of the global environment: the oceans, the atmosphere, and land. There is increasing evidence that global environmental change can harm human health through a variety of direct and indirect pathways leading from these accelerations.

Changes to two sets of trends have been used to monitor the Great Acceleration. These include socio-economic trends (e.g. the rise in population numbers, human lifespan and urbanization), alongside Earth system trends (e.g. an increase in the levels of carbon dioxide in the atmosphere, average global temperature, tropical forest loss, and ocean acidification). The fact that many indicators under both trends have increased side-by-side points to a cause-and-effect relationship, and concern that the rate of increase observed at present cannot be maintained indefinitely. Major adaptations to the drivers of these trends, such as the use of cleaner energy and the development of more efficient agricultural practices, will be needed to ensure that the environment is not permanently damaged. Figure 2(a) below captures Earth system trends, while Figure 2(b) captures the socio-economic ones.

# The Great Acceleration: Earth System Trends

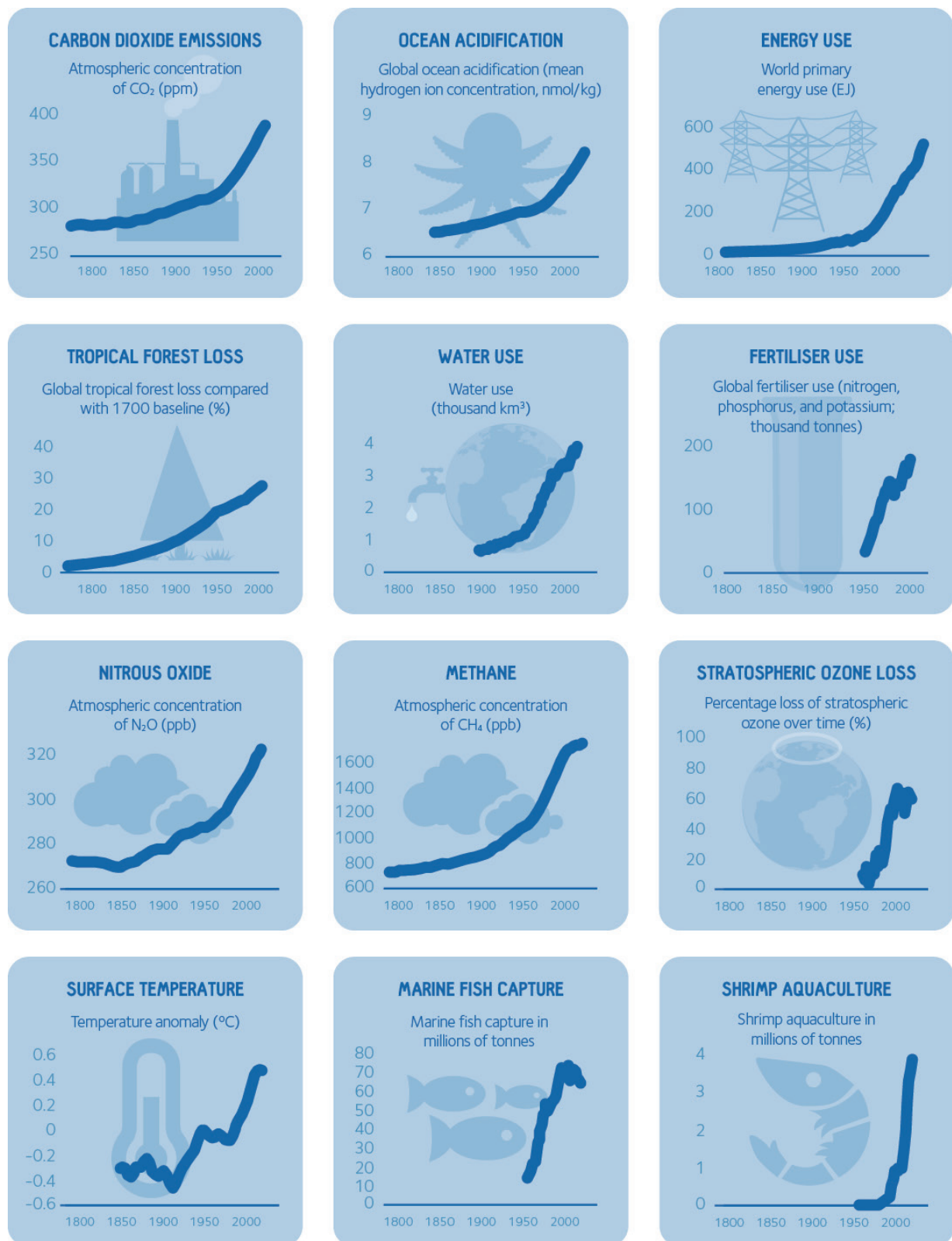


Figure 2a: The concurrent increase in a number of socio-economic and Earth system trends shows the inter-related impacts of human activity on the planet, at a global level, over recent time. Most trends started at the beginning of the Industrial Revolution in Europe, but have accelerated dramatically since the mid-20th century.

## Socio-economic Trends



Figure 2b: This impact has been particularly dramatic since 1950. Many trends, including domestication of land, population, use of transportation and biosphere degradation are now accelerating at a pace that cannot be sustained without major systemic change. Steffen et al (2004)

## 2.0 State of Play of Human Health

### 2.1 Trends across Time and Place

To understand how human health is impacted by the environment, it is important to first understand recent trends in human health, and second to understand the environments we live in and how these factors interact. Causes of and vulnerability to ill-health combine often in a complex and place-specific manner.<sup>19</sup>

Children born in developed countries today can expect to live more than 80 years. Global death rates for under five-year-old children dropped from 214 per 1000 live births in 1950-1955 to 59 per 1000 in 2005-2010. It has now dropped below 2 in 1000 in some European countries, Singapore, and Japan. Contrast this with pre-Industrial Revolution Europe, where roughly 25% of infants died before their first birthday and 40-50% of the population died before the age of 10. At the end of the 17th century, only 20% of people living in Amsterdam were over 50,<sup>20</sup> whereas in 2017 the figure was closer to 40%. Living until 90 is no longer uncommon in many developed countries.

Something has changed in the last 350 years, clearly, but it has not changed everywhere. Global average life expectancy increased from 47 in 1950-1955 to 69 in 2005-2010, and stood at just over 71 in 2015, but ranges from nearly 90 in some countries to barely 50 in others. Global average under-five mortality dropped from 21.4% of live births in 1950-55 to 5.9% in 2005-2010 and to 4.1% in 2015, but again there is a wide range – from 0.2% in Iceland to 13.3% in Somalia.<sup>21</sup>

While the extent of the change has been most dramatic in Western Europe, North America, Australia, and Japan, many central African countries today bear an uncomfortable similarity with 17th century Europe. What is different about the environments we lived in 350 years ago and those that some of us live in today? And what is different about the environments in which the average person today lives to be nearly 90, and those in which the majority would count themselves lucky to reach 50? Countries with a low life expectancy also tend to be those with high rates of neonatal and under-five mortality (see *Table 1*), which begs the question of what makes some places inherently less healthy across an entire human lifespan than others?

**Life expectancy:  
Global average**

1800-1950	– 30-40
1950-1955	– 47
2005-2010	– 69
2050	– 80+?

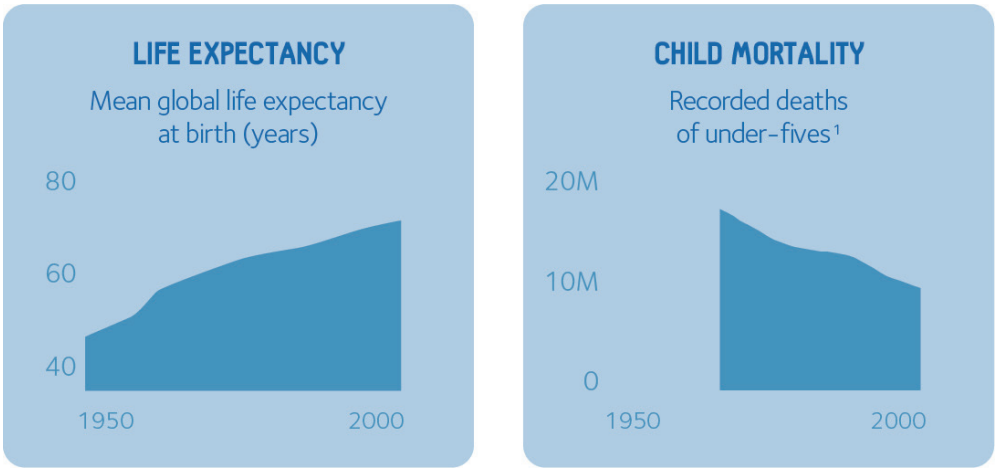


Figure 3: Our chances of surviving childhood and living into old age have increased significantly in recent decades, but many countries still lag far behind the global averages. Source: Whitmee et al (2017)

Country	Life expectancy	Neonatal mortality per 1000 live births
Japan	83.70	0.9
Switzerland	83.40	2.9
Singapore	83.10	1.1
Australia	82.80	2.2
Spain	82.80	2.0
Global average	71.4	18.6
Côte d'Ivoire	53.30	36.6
Chad	53.10	35.1
Central African Republic	52.50	42.3
Angola	52.40	29.3
Sierra Leone	50.10	33.2

*Table 1: Countries with the longest life expectancy at birth (those highlighted in light grey) – tend to have very low rates of neonatal mortality, while those with the lowest life expectancy at birth (highlighted in darker grey) have high rates of neonatal mortality. Some countries are clearly healthier from birth to death. (Source: WHO/GHO 2015)*

Such startling differences raise challenging questions about why gains that have been made in some countries are not being felt equally around the world. Nor are they being felt equally across all socioeconomic or ethnic groups, or regions, within a country. For example, white Americans had an additional 3.6 years of life expectancy at birth compared with black Americans in 2012, while Hispanic Americans had a life expectancy advantage of 3.0 years over non-Hispanic white Americans and nearly seven years over non-Hispanic black Americans<sup>22</sup>. In Scotland, UK, a life expectancy advantage at birth of more than 10 years has been observed between men in the most well-off segments of the population and those least well-off,<sup>23</sup> with marked differences even between wards of the same city.<sup>24</sup>

**Gains that have been made in some countries are not being felt equally around the world. Nor are they being felt equally across all socioeconomic or ethnic groups, or regions, within a country.**

Neonatal mortality, under-five mortality, and life expectancy are all closely tied to economic factors, in particular a country's GDP per capita and health spending per capita (see Figures 5a and 5b in the following section).

People born into lower-income economies, or lower-income households within an economy are more likely to face health challenges throughout their lives. This link with the economy remains apparent in the changes that have resulted from this dramatic increase in life expectancy in recent decades, explained through the demographic transition and the epidemiological transition, covered in the following section.

#### Some factors in health inequality

**Ethnicity:** In 2012, white Americans had an additional 3.6 years life expectancy compared with black Americans.

**Income:** In Scotland, men from the top fifth income group have a life expectancy advantage of 10 years over men from the lowest fifth income group.

**GDP:** Neonatal mortality, under-five mortality and life expectancy all show a linear improvement with a nation's GDP.

**Government investment in healthcare:** Health improves more rapidly with increased public spending per capita on healthcare than with GDP alone.

## Global Average Life Expectancy: 1800, 1950 and 2011

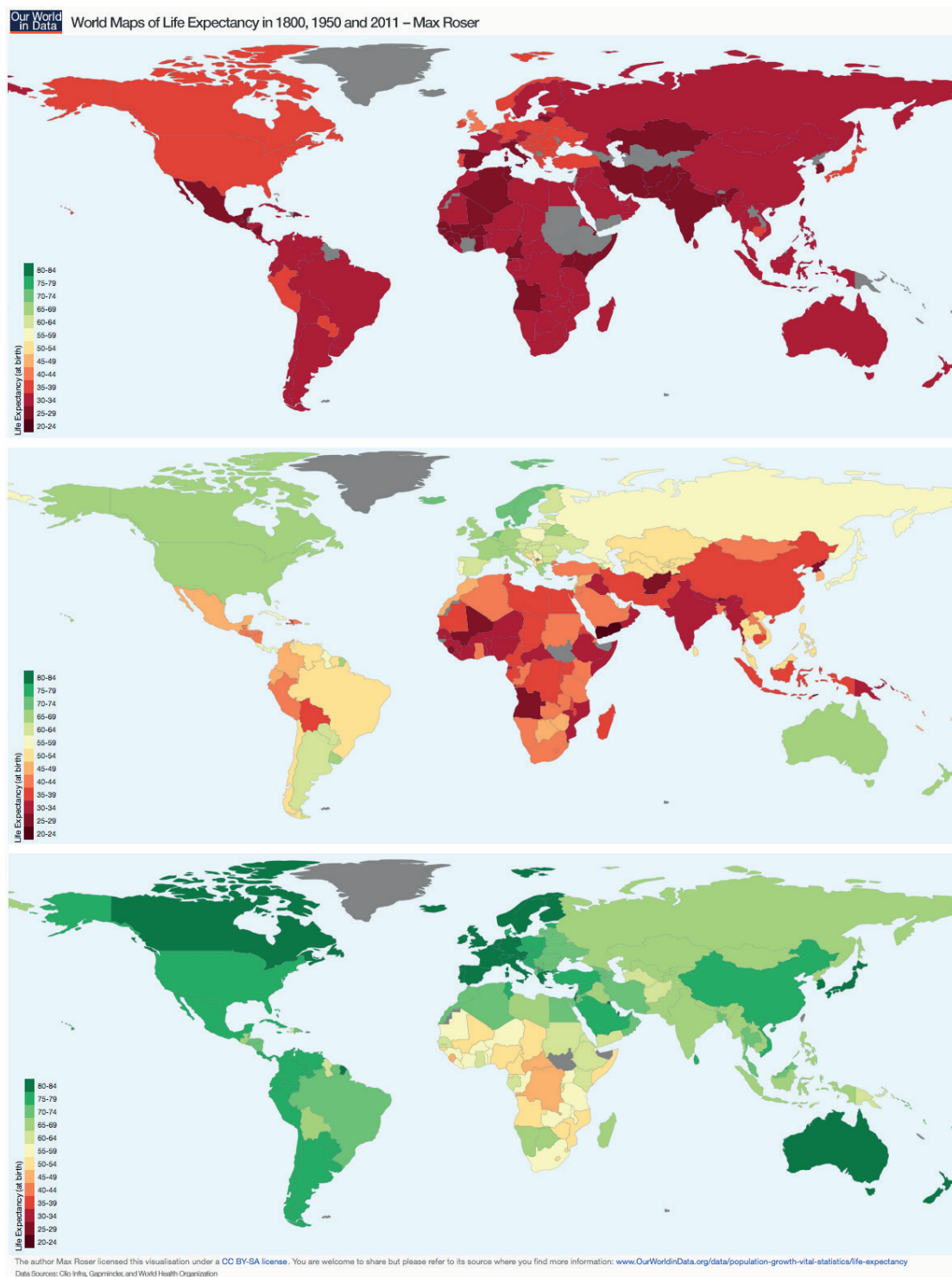


Figure 4: Life expectancy changes worldwide since 1800. As life expectancy increases in industrial Europe and North America, Africa and Asia lag behind. Asia is now catching up, but life expectancy in sub-Saharan Africa remains low in many countries. (Source: Our World in Data.)

# Life Expectancy, GDP Per Capita and Health Spending in OECD countries

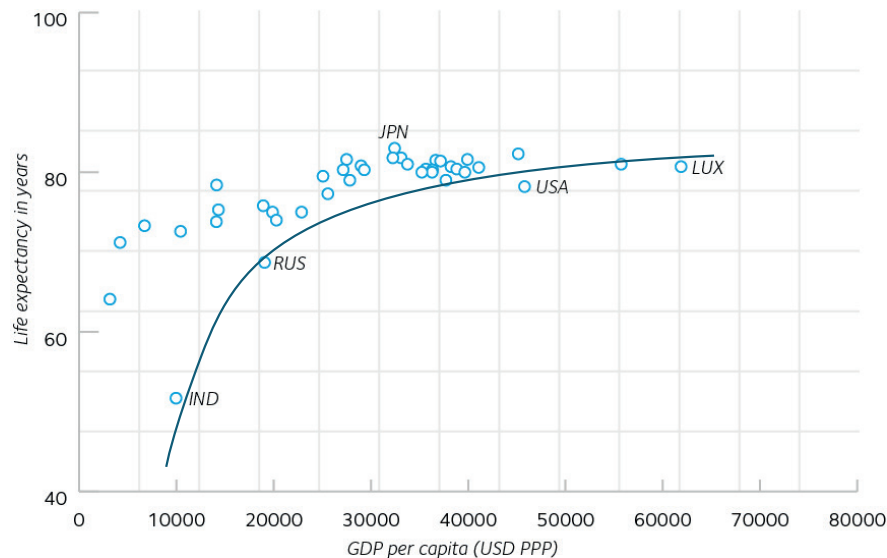


Figure 5a: Life expectancy in OECD countries improves rapidly with increased GDP per capita.

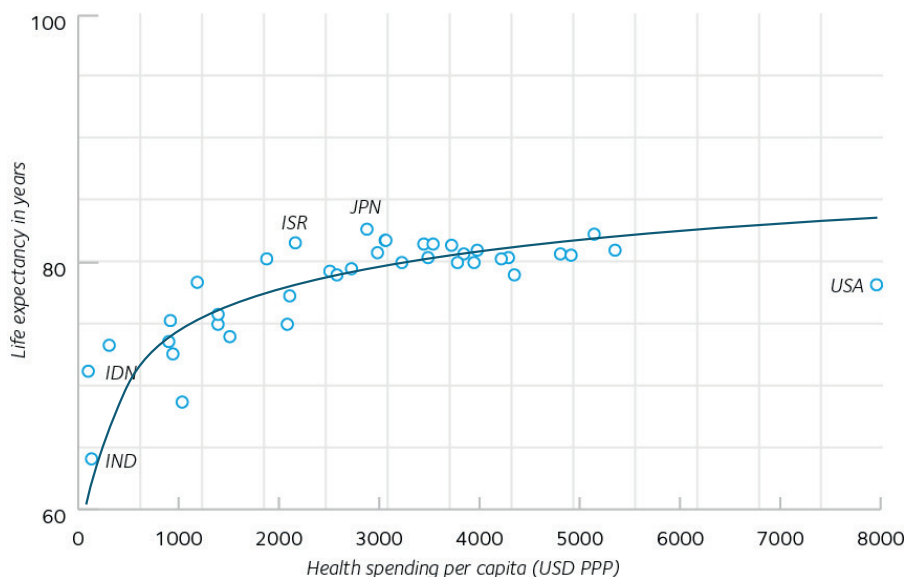
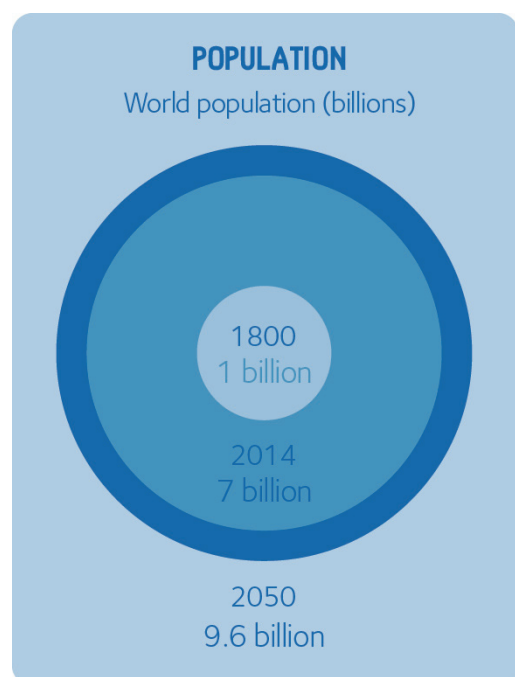


Figure 5b: Life expectancy improves more sharply with health spending per capita than with GDP.  
(Source: OECD Health at a Glance)

Life expectancy at birth in the 35 countries of the Organisation for Economic Co-operation and Development (OECD) shows a close positive correlation with GDP.<sup>16</sup> The BRIC nations (Brazil, Russia, India and China), and particularly India (IND) and Russia (RUS), lag behind the more developed regions of Europe, North America, and Japan. There is an even stronger positive correlation between life expectancy and health spending per capita, with a similar lag behind Europe for the BRIC nations. The United States is an interesting outlier: health spending per capita is higher, but this delivers only the same level of life expectancy enjoyed in “poorer” regions such as Eastern Europe and South America: around 77–78 years for men, and 81 for women.<sup>25</sup>



## 2.2 The Demographic Transition

As children become more likely to survive to adulthood and people begin to live longer in general, the age distribution of the population changes: the **demographic transition**.<sup>26</sup> Populations change from high numbers of young people and low numbers of elderly, to a more even distribution across all age groups. This transition began in Europe in the 18th century, concurrent with the Industrial Revolution, and its five identified stages are closely linked to economic and technological development. Most European countries have now completed Stage 4, as have others such as Japan and the US, but the transition has not happened simultaneously in all regions of the world. Many developing countries, particularly those in sub-Saharan Africa are still in Stage 1.

**Population increase in the 20th century has been linked to four key factors: food, housing, sanitation, and medical progress.**

Countries still in Stage 1 are invariably low-income economies; those in Stages 2 and 3 are low-middle and upper-middle, and high-income economies are in Stages 4 and 5. Populations in each stage have a distinct health profile, explained on the next page.

### The demographic transition in 5 stages

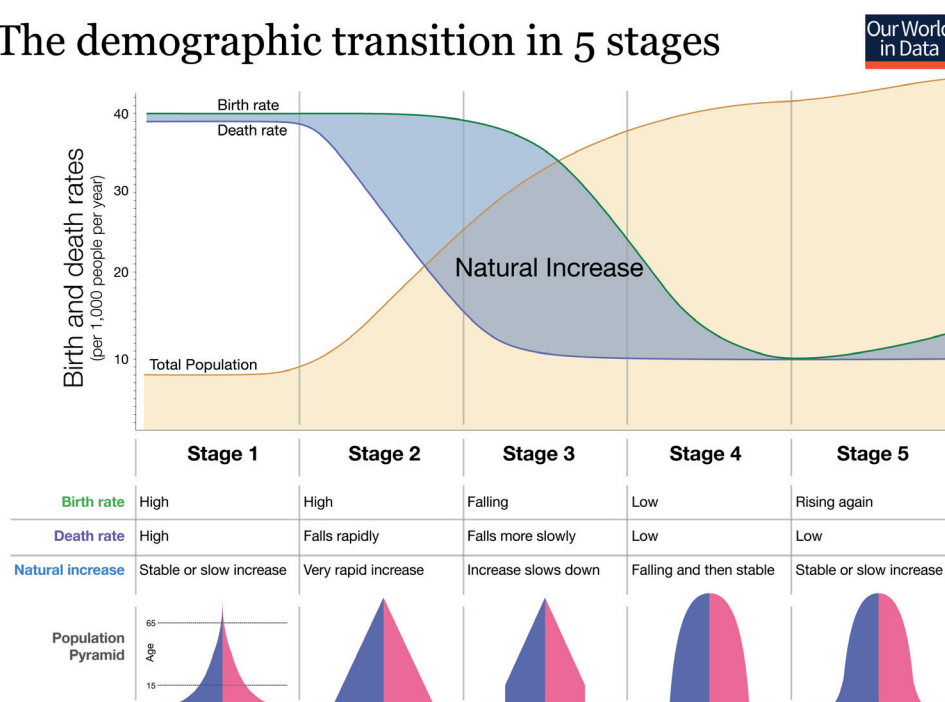


Figure 6: As rates of neonatal, infant, and childhood mortality drop, the structure of the population changes to a more even age distribution. (Source: Our World in Data)

## Stages of the Demographic Transition

*Stage 1:* Stage 1 is epitomized by a high birthrate and high childhood mortality, with a steady decline in numbers of people reaching older ages. Only a small percentage of the population is over 65. For all age groups, the main causes of death tend to be disease and malnutrition. The steep-sided demographic pyramid of Stage 1 was typical of Europe and other now-developed countries prior to the mid-20th century and persists in the 21st century in developing regions, particularly those with a high rural to urban population ratio and low-income economies. Examples of countries showing this distribution include Sierra Leone, the Democratic Republic of Congo, and Afghanistan.

*Stage 2:* As Stage 2 begins, the shape of the pyramid changes as more children survive childhood. The fertility rate drops (from five-plus children per mother to around two), and people become less likely to die before reaching old age. This is usually concurrent with several environmental changes happening in the associated countries, including advances in hygiene and sanitation which, along with medical developments such as vaccination and antibiotics, mean that fewer people die from infection. The introduction of safer working practices protects adults – particularly men – from death due to accidents in early and mid-adulthood. As economic development and increasing GDP lifts people out of absolute poverty, food security becomes less of a problem. The percentage of the population living in cities increases; however, this can increase exposure to health risks such as air pollution, heat stress, and poor sanitation. Examples of countries showing this distribution include Turkey, Saudi Arabia and India.

*Stage 3:* Stage 3 is a continuation of Stage 2, as those who have survived childhood begin to reach old age and smaller families become the norm. Examples of countries in this stage include Mexico, Chile and Georgia. If the birthrate drops very quickly, the bottom section of the pyramid can become thinner than the middle, with higher numbers of the population in middle-age than in childhood or old age. Estonia and China are amongst the countries currently showing this distribution.

*Stage 4:* In Stage 4, the evening out of the age distribution at the bottom of the pyramid seen in Stage 3 has worked its way up, as people born in a period of high childhood survival begin to reach old age. This stage is associated with fully developed, modern societies in which good sanitation and hygiene ensure that serious infections are rare; access to healthcare offers vaccination against or treatment for many causes of ill-health, including cancer and diseases more likely to affect the elderly. Starvation due to extreme poverty has been eliminated. Most of the population survives at least into their mid-late 60s. Examples of countries showing this distribution include most European countries, the US, and Chile.

*Stage 5:* Stage 5 is largely hypothetical at present, but considers what might happen to populations once the age distributions have stabilized in Stage 4. The hypotheses cover a “more fertile” model, in which the birthrate may begin to increase again, and a “less fertile” model, in which the birthrate drops below replacement level, creating a bulge in the middle of the pyramid. The less fertile model appears to be characteristic of countries that go through stages 3 and 4 very rapidly, such as Japan, Russia, and China, over one or two generations. This has been described as a potential second demographic transition<sup>27</sup> in which populations may shrink, rather than continue to grow.

This demographic transition has fuelled the rapid global population increase seen in the Great Acceleration since 1950. Global population grew at a rate of less than 0.05% from 10,000 years ago to the late 18th century. It stood at around 1 billion in 1800 but reached 3 billion in 1959; this has increased to around 7 billion today and is projected to reach around 9 billion by 2050.

Population increase took off in the early 20th century as living standards in many countries improved: it has been linked to four key factors: reduced variability in the food supply, better housing conditions, improved sanitation and, later, progress in preventative medicine<sup>28</sup> (e.g. vaccines) and cures (e.g. antibiotics and cancer treatments).<sup>29</sup> Agriculture and urbanization removed many of the common risk factors for disease and ill-health. As the age structure of the population changes, however, so too do the types of health challenges it encounters. This is known as the **epidemiological transition**,<sup>30</sup> which will be covered in the next section.

## 2.3 The Epidemiological Transition

As populations live longer, the main causes of ill-health and death also change. This epidemiological transition can be divided into three stages<sup>31</sup>.

*First epidemiological transition:* Away from the “age of pestilence and famine”, characterized by a move from pre-agricultural, historical, and undeveloped hunter-gatherer societies in which starvation and plagues are the main causes of death, to an early agricultural/urbanized society where increased contact with animal and human waste spreads disease, particularly through contaminated water supplies and overcrowded conditions.

*Second epidemiological transition:* A transition to the “age of receding pandemics”, in which infectious disease has receded as a cause of death. This has been due to a combination of cleaner conditions, including better hygiene and sanitation, along with better food security and storage, increased medical care, early vaccination, and better living conditions in general.

*Third epidemiological transition:* A transition to the “age of chronic disease”, where chronic degenerative diseases such as cancer and heart conditions are the main causes of death. Some of this transition is an inevitable consequence of an ageing population, as diseases such as cancer, Alzheimer’s, and dementia, are more likely to be experienced. However, much is also attributable to the environment in which populations live, and the health risks they are exposed to within it, combined with the ease with which they can access – and afford – healthcare. Causes of death differ greatly between different regions of the world, as well as between different socio-economic groups within the same region.

The World Health Organization breaks down the causes of death into three main groupings:

**Group I:** Communicable, maternal, perinatal, and nutritional conditions

**Group II:** Non-communicable diseases (NCDs)

**Group III:** Injuries and conflicts

Communicable diseases are infectious diseases that are spread by direct contact from one infected person to another (for example, chickenpox or influenza) or indirectly through vectors such as rats or mosquitoes (e.g. bubonic plague and malaria). They are caused by exposure to viruses and harmful bacteria.

Non-communicable diseases (NCDs) are not transmitted between people, but are conditions in which the body experiences an unhealthy state such as cancer, asthma, or diabetes. What causes NCDs is complex, but there is often a link with long-term exposure to risk factors such as poor air quality, harmful chemicals and toxins, and poor diet. The World Bank groups countries into four categories based on their gross national income (GNI) per capita: low income, lower-middle income, upper-middle income, and high-income countries\*. The 10 leading causes of death for each income group are different (see Figure 7).

### WHO disease groups

#### Group I

Infections, poor nutrition, childbirth complications

#### Group II

Cancers, heart disease, diabetes, respiratory illness

#### Group III

Injuries and conflicts

\* Low-income economy countries have a GNI of \$1,005 per annum or less; lower-middle income economy countries have a GNI of \$1,006–3,955; upper-middle economies have a GNI of \$3,956–12,235; and high-income economies have a GNI of \$12,236 or more.

### Top 10 causes of death per 100,000 population

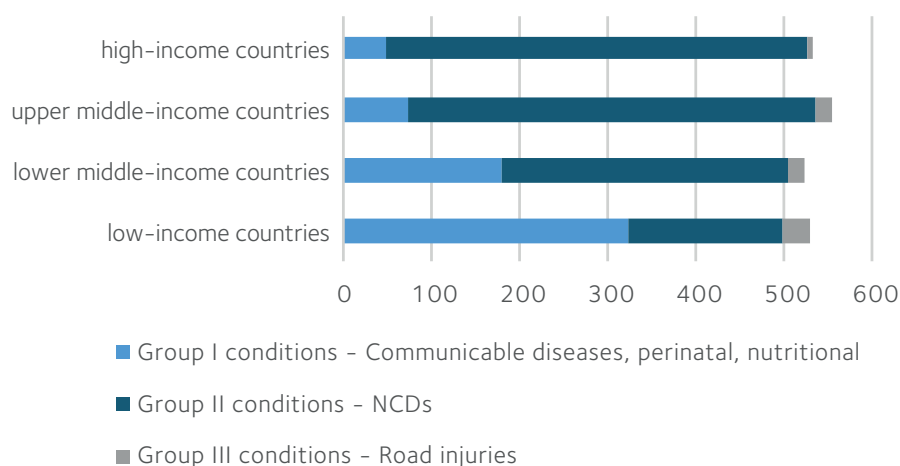


Figure 7: In low-income countries, the main cause of death is Group I conditions, but the ratio of Group I to Group II causes of death is reversed for higher income economies. (Source: WHO Global Burden of Disease Study 2015)

In low-income economies – developing countries that tend to be at Stage 1 of the demographic transition – the largest cause of death is from Group I conditions, particularly infection in early childhood. For example, in the Democratic Republic of Congo, diarrhoea, malaria, respiratory infections, HIV/AIDS, tuberculosis, and meningitis accounted for more than 50% of all deaths in 2012<sup>32</sup>. Measles were responsible for 5% of deaths in children under five in 2012, and in 2004 a measles outbreak in the west of the country was responsible for 4.6% of deaths recorded across all age groups that year<sup>33</sup>. Of 303,449 maternal deaths in childbirth globally in 2015, 281,190 (93%) occurred in low- or lower-middle income economies, as did 5 million of the 5.7 million deaths from infectious and parasitic diseases<sup>34</sup>.

These Group I diseases virtually disappear as a cause of death in high-income economies. They would disappear completely from the top 10 causes of death if not for the fact that lower respiratory conditions include pneumonia, a disease that disproportionately affects the very elderly, at ages well beyond the average life expectancy of most low-income countries. Respiratory conditions are also linked to air pollution, which can increase the severity of existing symptoms<sup>35</sup>.

In 2015, 70% of all the 56.5 million deaths – 40 million – recorded worldwide were due to the non-communicable diseases of Group II. The largest killers were:

- Cardiovascular disease (17.7 million deaths worldwide)
- Cancer (8.8 million deaths worldwide)
- Lower Respiratory Infection (3.2 million deaths worldwide)
- Diabetes (1.6 million deaths worldwide)

These Group II conditions are rarer in low-income economies. Such countries account for only 800,000 of the 17.7 million global deaths from cardiovascular diseases, 376,000 of the 8.8 million global cancer deaths, 544,000 of the 3.2 million global deaths from lower respiratory infection and fewer than 78,000 of the 1.6 million global diabetes deaths recorded.

As the economy progresses through lower-middle, upper-middle and eventually high-income status, other new conditions emerge, such as Alzheimer's and dementia, which are associated with later-life onset. This has been described as a further epidemiological transition associated with the extension of lifespan beyond, perhaps, what nature intended. Such conditions are still rare in lower-middle income countries, but have started to become part of the top 10 causes of death in upper-middle income countries, where they now account for 20 deaths in every 100,000 (60 per 100,000 in high-income countries). Ischaemic heart disease is present in low-income countries, but rates rise from 49 deaths per 1000 to 145 as income levels increase.

The causes of disease and mortality rates are closely linked to a country's level of economic development and its stage in the demographic transition. Group I conditions disproportionately affect the young in developing countries, as well as the infirm, the poor, and the excluded in more developed ones. They trap low-income economies, and post-conflict or disaster regions in the age of pestilence and famine.

Group II conditions are characteristics of the second and third epidemiological transitions, epitomized by later life, long-term conditions affecting those who have had the luxury of surviving childhood. The risk of death from infection and starvation is removed in such environments, only to be replaced by new risk factors such as exposure to pollutants and inappropriate diet. Group II diseases will inevitably be more prevalent in older populations: three out of every four cancers in the US are diagnosed in people over 55, and in the UK, half of all cancers are diagnosed in people over the age of 70. Alzheimer's and dementia are conditions that begin far beyond the life expectancy of most sub-Saharan African countries. Populations in the later stages of the demographic transition may therefore inevitably experience more Group II conditions, but some countries that have completed Stage 4, such as Japan, have much lower rates of cancer and diabetes than others, such as the US. This suggests that something more than just age is impacting on population health and the type of conditions experienced.

The drivers of exposure to the risk factors that increase vulnerability to Group II diseases, such as pollutants, poor diet, and poor air quality, result from a third mega-trend of human development and progress, which will be discussed in the following section, and which includes changes in land use and urbanization. These same drivers may also herald a further stage to the epidemiological transition – to a new age of emerging diseases<sup>36</sup> – in which infectious diseases begin to pose a threat once again as natural habitats disturbed by changes to land use and food production in previously remote and densely forested areas, push animal vectors into closer contact with human populations.

### Causes of death in 2015

70% of all 40 million deaths globally were from non-communicable diseases

Cardiovascular disease – 17.7 million

Cancer – 8.8 million

Lower respiratory infection – 3.2 million

Diabetes – 1.6 million

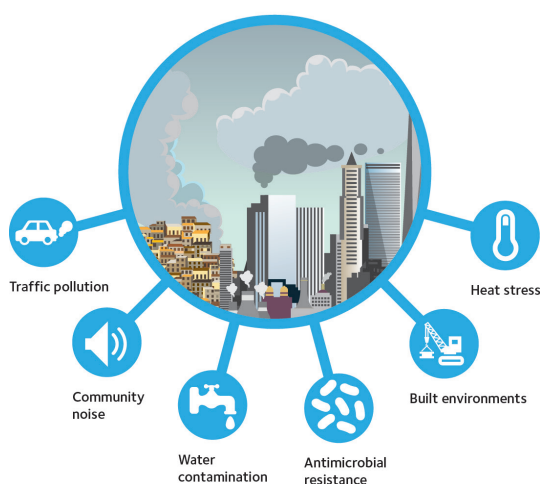
Source: World Health Organization

In recent years, this has seen diseases such as malaria and West Nile Fever reaching new regions,<sup>37</sup> and an increased incidence of new diseases being transmitted from animals to humans for the first time, as has been seen with Ebola.<sup>38</sup> The risks are further exacerbated by the increasing resistance of pathogenic bacteria to antibiotics, which may make future infections harder to treat.<sup>39</sup> This age of emerging diseases threatens to undermine a final stage of the epidemiological transition that would otherwise be an “age of medical technology” and/or an “age of sustained health”,<sup>40</sup> in which medical progress confers a significant health advantage on future generations, with all members of society surviving into extreme old age.

## 3.0 Human Progress

### 3.1 Overall picture

As the global population has risen, people's relationship with the natural world has changed. Cities and agriculture emerged 10,000 years ago, enabling humanity to move away from a hunter-gatherer existence towards more sophisticated societies. Throughout this transition, agriculture has stabilized humanity's food supply, strengthening human health and resilience. Urbanization has allowed economies of scale and resource efficiencies to be achieved<sup>41,42</sup> and cities with strong public health measures and medical systems have prolonged human life. However, there is an urgent need to reduce the environmental footprint of both cities and agricultural systems. While widespread access to electricity has also been key to human progress, the dominant energy paradigm – primarily based on fossil fuels – led to climatic changes at a rate that is unprecedented in recent geological time. This risks harm to human health and could possibly endanger human survival.



### 3.2 Urbanization

Whether urbanization drove agriculture or vice versa is a difficult question to answer<sup>43</sup> but the two go side-by-side in a history intertwined with environmental change. Civilization – complex societies characterized by greater urban development – emerged around 10,000 years ago alongside a marked decrease in rainfall in the north of Africa. This appears to have created conditions that pushed human hunter-gatherer communities towards larger settlements supported by irrigated agricultural land and more complex social systems.<sup>44</sup> Since then, increasingly larger cities have developed across the world. The percentage of the world's urban population has increased from 3% in 1800, to 14% in 1900, 30% in

1950, and 50% in 2015. By 2050, an estimated 70% will live in urban areas<sup>45</sup> and one in three of those in a city with more than 500,000 inhabitants.<sup>46</sup> In China, 80% of the population is expected to live in urban areas by 2050.<sup>47</sup>

Cities allow for greater connectivity, economies of scale, and resource efficiency, presenting many benefits for mankind. Their overall contribution to human health has been positive. Condensed living space reduces energy use and water use,<sup>48</sup> allowing more of the natural environment to be preserved. However, urban areas often become polluted, and crowded living conditions can enable diseases to spread more quickly. Urban development and expansion needs to be carefully managed to preserve the health of the environment both inside and outside the city, as well as the health of the urban inhabitants.

Cities create several challenges to human health. They can be dirty environments in which waterborne diseases proliferate, including the bacteria and viruses that cause diarrhoeal disease. Diarrhoea causes 1.4 million deaths a year and was the world's eighth biggest killer in 2015.<sup>49</sup> Crowded conditions facilitate the spread of other infectious diseases such as measles, influenza, and chickenpox.<sup>50</sup>

The consumer lifestyles of city dwellers and the high concentration of vehicles creates problems with waste and air pollution. New and growing cities need proper urban planning. In developing countries, 98% of urban areas fail to meet WHO air quality guidelines; in developed countries the figure is 50%. Cleaner, more sustainable cities such as Oslo in Norway<sup>51</sup> and Curitiba in Brazil<sup>52</sup> provide blueprints for the further reduction of environmental footprints in future.

### The world's megacities are set for major growth

Population growth of the world's megacities (millions, 2011–2025)

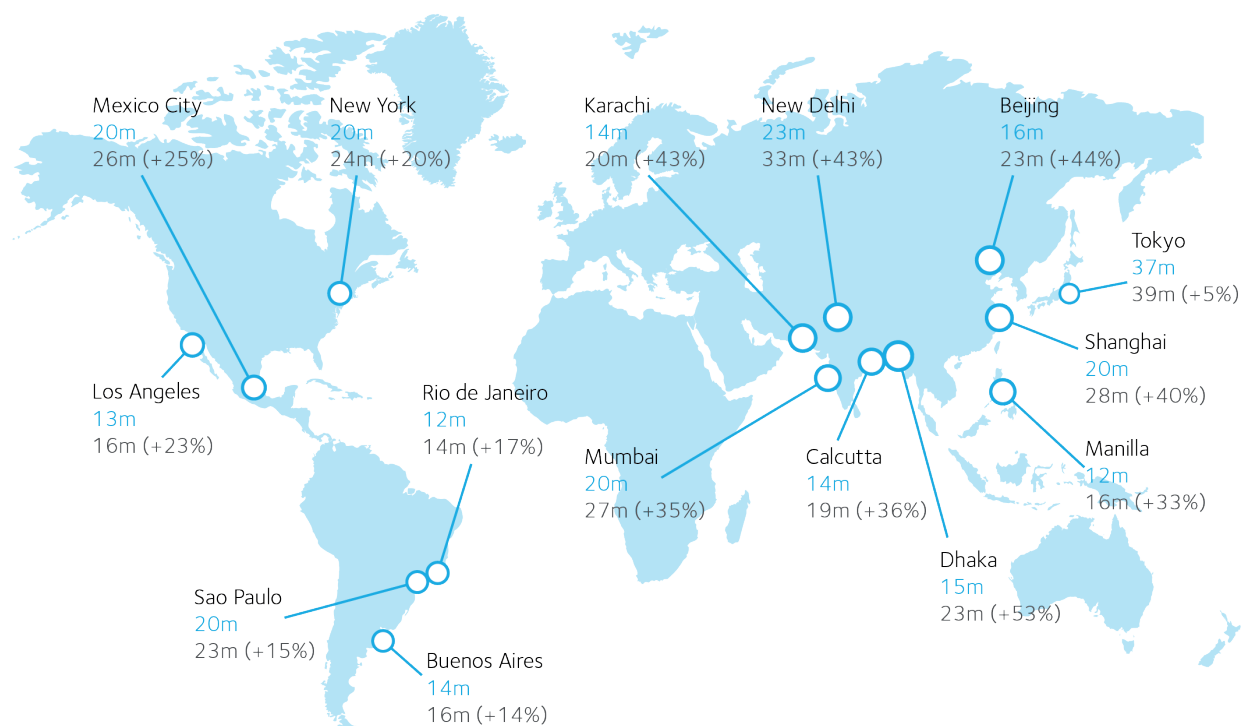


Figure 8: Projected population growth in the world's 15 largest cities, 2011–2025. The number of cities and megacities worldwide is growing, as well as the size of their populations. (Source: Statistica.com)

In pre-industrial Europe, before the advent of large-scale vaccination and good sanitation (particularly due to piped and disinfected water supplies), an 'urban penalty' resulted in lower life expectancy in cities than in rural areas.<sup>53,54,55</sup> For example, in 19th century England, urban children were 2.5 times more likely to die than rural children, and urban men between the ages of 35 and 60 had considerably lower life expectancy than their rural counterparts. The urban poor were often particularly affected,<sup>56</sup> and this continued even after sanitation and medical interventions were introduced, as access to mitigations is often income-dependent. In Spain in 1900, there was a difference of nearly seven years in life expectancy at birth between the populations of provincial capitals and rural areas and, in 1930, diseases of the digestive tract and respiratory tract were 75% higher in urban areas than rural ones.

As conditions in cities improved, however, the higher exposure to risk factors in the urban environment was eventually overtaken by the benefits conferred by higher incomes and better access to essential services and

opportunities<sup>57</sup>, providing a clear urban advantage. This is particularly true in the case of health, where healthcare services and providers in the form of highly skilled nurses and doctors are clustered in well-equipped city hospitals. High economic growth supports medical research, development, and healthcare systems.

Historically, the urban penalty has been more likely to affect countries during the early stages of the demographic transition, turning towards an urban advantage for physical health as those countries develop. Inequalities today, however, are not only due to poor sanitation and crowded urban conditions that facilitate disease spread. There is also a form of the urban penalty/urban advantage nexus linked to socio-economic status, in which rates of NCDs and respiratory disease, as well as some Group I diseases such as tuberculosis and parasite infection, disproportionately affect the urban poor.<sup>58</sup>

In developed countries, there is some evidence that while the urban penalty has been reversed to become an urban advantage, this may now be shifting once again as some high-income rural areas are outperforming their urban neighbours. At the intra-national level, Scotland's Public Health Observatory<sup>59</sup> records that remote rural areas have the highest life expectancy: 79.5 years for males and 82.8 for females, with life expectancy decreasing as living becomes more urban. Such trends may be due to wealthier members of a very urban society moving back to the countryside, combined with an evening out of good access to healthcare services between rural and urban areas. At this micro-level, it is often the marginalized poor within high-income urban settings who have the worst health outcomes.

### **An unfinished public health agenda**

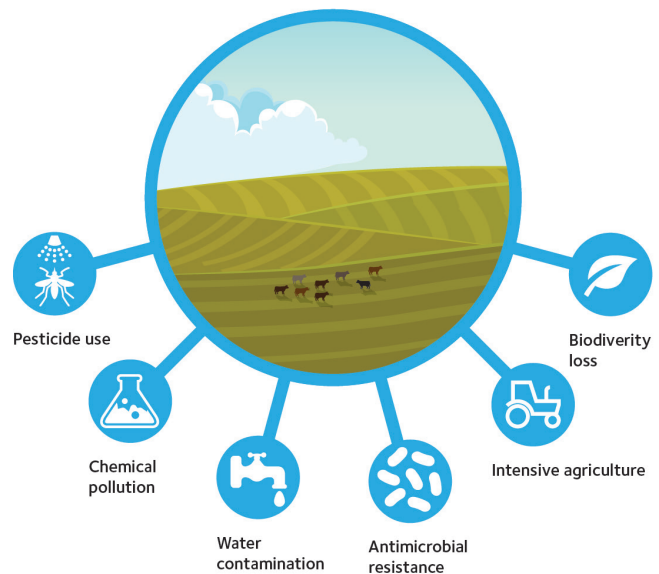
Health is clearly dependent on healthcare infrastructure and good access to it. While this tends to be centralized in major cities, some countries have barely begun to build the infrastructure on which healthy urban living depends, let alone the healthcare infrastructure; more than 844 million people (more than 10% of the global population) do not have clean drinking water and 2.3 billion (about one-third) do not have adequate sanitation. This points to an unfinished public health agenda in much of the developing world. The demographic transition of the urban poor lags behind that of the population overall, and the epidemiological transition can simultaneously place a higher burden of Group I, II and III diseases on lower socio-economic groups.

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Africa and much of Asia has yet to go through the same transformation in public health that took place in European and North American cities in the late 19th and early 20th centuries.<sup>60</sup> The poorest people in developing countries now face a triple burden of communicable disease due to inadequate sanitation, lack of access to healthcare services including vaccination programmes, and increased risk of exposure to urban and industrial pollution. As cities develop, behavioural illnesses driven by poverty such as smoking, excess salt and alcohol consumption, poor housing, and unsafe working conditions also add to the urban penalty. If unaddressed, the health burden in such environments is likely to considerably impact government budgets in developing countries over the coming years, threatening to destabilize economic and social development.

### 3.3 Agriculture and Land Use

The introduction of agriculture alongside the emergence of cities has enabled those cities to grow and prosper. Humanity has been able to settle, freed from subsistence existences by a more secure and centralized food supply enabled by irrigation and farming practices. The ability to store surplus for the winter and against times of scarcity offers insurance against environmental conditions and, once not every member of society is engaged in food production, the stratification of urban society enables scholars, engineers, scientists, and doctors to emerge.<sup>61</sup> Like the growth of cities, agriculture has been overwhelmingly positive for humanity.



Agriculture – defined as the science and practice of farming, including cultivation of the soil to grow crops, and the rearing of animals to provide food, wool, and other products – brings with it dramatic changes in land use, water systems and, in more modern times, large-scale use of fertilizers and pesticides. This can drive global environmental change. Agriculture has also separated humans from nature,<sup>62</sup> as most members of society become food consumers rather than producers.

**Humans currently use more than half of the Earth’s habitable surface for agricultural production. Three-quarters of this is used to graze animals or produce food for those animals, and only one-quarter for direct human food consumption.**

Cities and large-scale agriculture appear virtually simultaneously in the historical record. From 10,000 BCE onwards, converted cropland increased gradually to 500 million hectares by around 1,000 BCE. Since then, land has been converted to cropland, and to graze animals, at a much faster rate, and now stands at nearly 5 billion hectares: 80% of this conversion has happened over the last 300 years, and 50% has happened since 1900.<sup>63</sup> The rate has slowed recently as technological advances have enabled greater yields to be achieved from the available land. In 5,000 BCE, there were 2.3 hectares of domesticated land per inhabitant, decreasing slowly to 1.5 hectares per person until the middle of the 20th century and declining sharply since then to around 0.67 hectares per person in 2015. However, this has come at the expense of greatly increased use of fertilizers, and the loss of biodiversity and micronutrients.

#### Domesticated land increase

From 500 million hectares in 1000 CE to 5 billion hectares today.

80% of land conversion throughout history has happened since 1750

2.3 hectares of domesticated land per person in 5000 BCE

1.5 hectares per person in 1950

0.67 hectares per person in 2015

Agricultural soils contain 25–75% less organic carbon than those in comparable natural ecosystems such as undomesticated meadowland.<sup>64</sup> While just 1–3% of the Earth’s surface is covered by urban infrastructure<sup>65</sup> (0.05 billion hectares of the Earth’s surface), 1.3 billion hectares are dedicated to cropland and 5.3 billion hectares to grazing food animals that feed growing populations.

The large-scale agriculture that comes with a shift from subsistence farming to urban living causes deforestation, soil degradation, biodiversity loss, and risks releasing pollutants into the environment through the poorly managed use of fertilizers. While humans have become more efficient at using land, the fact that the world population has risen means that more land has been required over time to feed rising numbers of people. Humans currently use more than half of the Earth’s habitable surface (i.e. land that is not sea, ice, or desert) for agricultural production. Three-quarters of this is used to graze animals or produce animal feed, and only one-quarter for direct human food consumption. The amount of land available for agriculture is running out, requiring improved yields from current land use if future populations are to be fed adequately. Improved yields are possible: over the past 60 years, US corn production has quadrupled while the area used to produce it has only increased by half. According to OECD data, US agricultural practices yielded on average 11.0 tonnes of maize per hectare and 5.6 tonnes of rice in 2016, whereas Indian practices yield only 2.8 tonnes of maize and 2.4 tonnes of rice. However, countries where yields are higher tend to use more artificial fertilizers, pesticides and genetically modified seeds. All three of these impact on pollution and biodiversity loss, explored in the next chapter.

Rural and urban areas do not have to be separated – in 1996, an estimated 800 million urban dwellers grew food or raised livestock<sup>66</sup> – but urban centres are mostly supplied by large-scale, industrial agricultural that has a damaging impact on water and soil systems.

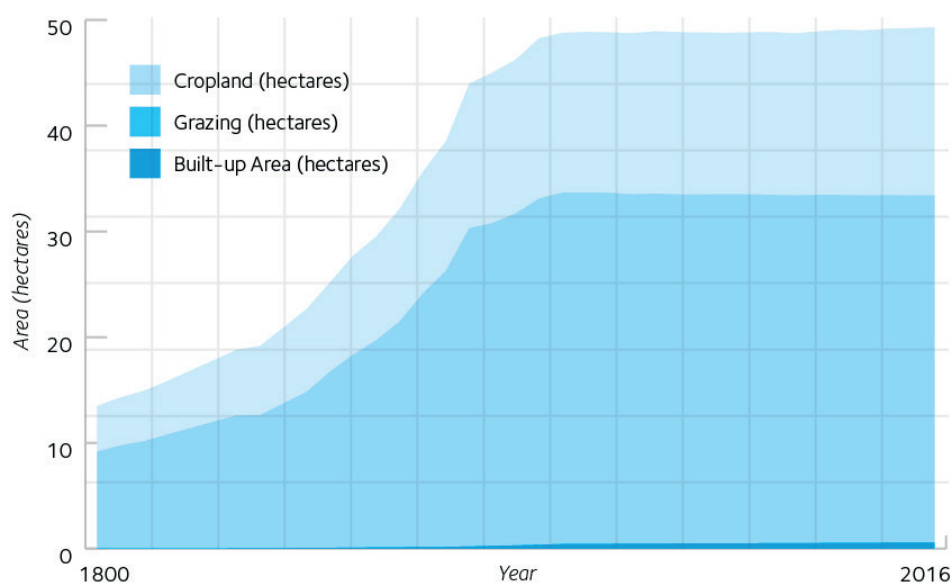


Figure 9: Land has increasingly been domesticated, though the amount needed per person has fallen. Built up urban areas account for a relatively small amount of land cover, though their existence drives the more dramatic land use changes needed to sustain urban food systems. (Source: Our World in Data)

A second important interaction between the agricultural economy and the environment is the impact of livestock. As well as the amount of land needed for grazing, food animals are a major source of greenhouse gas emissions – 7.1 gigatonnes (Gt) of CO<sub>2</sub> equivalent each year according to the UN Food and Agriculture Organization (FAO). This represents 14% of all annual anthropogenic emissions. Of this total, approximately 44% is in the form of methane, 29% is nitrous oxide and 27% is CO<sub>2</sub>. Cattle alone are responsible for 65% of these emissions. Producing 1kg of beef results in almost 300kg of CO<sub>2</sub> equivalent per 1kg of protein produced, which is higher than for other livestock animals: producing chicken meat and eggs, pork and cows' milk – without beef – all result in emissions below 100kg per CO<sub>2</sub> equivalent per 1kg of protein produced.

Better farming practices and techniques can reduce this impact. The FAO points towards improving feeding techniques and using better quality feeds, which can reduce the amount of methane generated during digestion and manure decomposition. Manure can be collected and reused as natural fertilizer: this recycles nutrients and energy and off-sets the emissions from livestock against the environmental damage that would otherwise be caused by artificial fertilizers. Improved management of grazing land could also off-set the emissions through carbon sequestration, by approximately 0.6 Gt of CO<sub>2</sub> equivalent a year.

In 2013, the FAO estimated that by improving current practices, the farming industry could reduce global greenhouse gas emissions from livestock by approximately 30% annually, particularly in the developing world: by 38% in South Asian mixed dairy systems, 19–30% for specialized beef production in South America, and 27–41% for West Africa's small ruminant sector.

Improving animal health care will also help to reduce impact through smaller and more productive herds. Overcrowded conditions mean that infections can spread quickly through livestock, particularly if conditions are not particularly hygienic, but the use of antibiotics to prevent and treat animal infections drives antimicrobial resistance

and impacts on the efficacy of antibiotics for human healthcare. An even bigger problem is the use of antibiotics as growth promoters, which also drives antimicrobial resistance. Improved hygiene practices, better animal welfare, and more rational antibiotic stewardship is needed to address this. So too can reducing the amount of meat in our diets with plant derived protein, the production of which is less environmentally damaging.

#### **Agriculture and water systems**

Irrigation helps crops grow in regions where rainfall alone is not sufficient, improving food availability and security, but this can also have a damaging impact on water systems. Agriculture diverts rivers, uses additional water, depletes soil nutrients, pollutes water bodies with fertilizers and pesticides, reduces marine biodiversity, and disrupts ecosystems. Irrigation uses much greater volumes of water than natural systems and accounts for around 70% of all water used globally.

Worldwide, groundwater is being extracted faster than it can be replenished, with 20% of it used for irrigation.<sup>67</sup> The most depleting



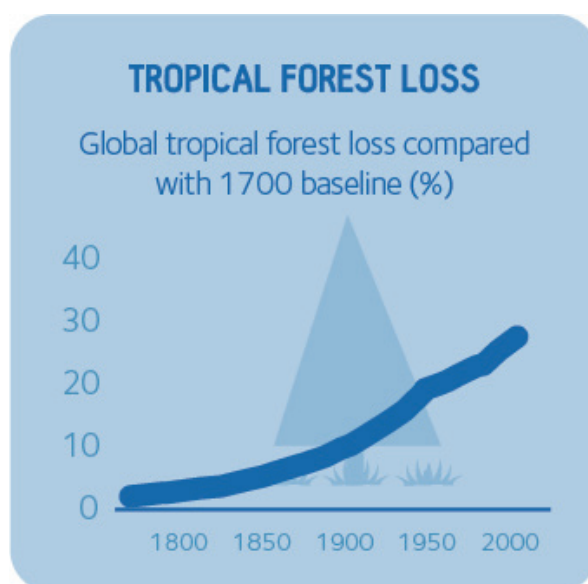
regions of the world are those with the highest agricultural production, including north-west India, north-east China, mid-western USA and California's central valley. Better water management, including the reuse and recycling of wastewater captured by improved sanitation practices and sewer systems can ease the pressures, but this requires adequate water treatment processes to ensure human health is not put at risk.

### Agriculture and deforestation

Perhaps the biggest effect that agriculture has had on the environment is its destruction of forests, which play a vital role as carbon sinks. Approximately 80% of above-ground terrestrial carbon and 40% of below-ground terrestrial carbon is stored in forests; forest cover is essential to the removal of CO<sub>2</sub> released by burning fossil fuels. During the early days of the Roman Empire, more than 90% of Europe was forested, but more than 99% of this primary forest has since been lost. A total of 50% of the world's tropical forest has been lost since the turn of the 20th century. Of an original 1.5 billion hectares, only 700 million remain.<sup>68</sup>

**A total of 50% of the world's tropical forest has been lost since the turn of the 20th century. Of an original 1.5 billion hectares, only 700 million remain.**

Forests and their ground cover conserve water, prevent flooding and reduce run-off. This helps prevent toxic agricultural chemicals from entering the food chain and water systems. Trees control soil erosion and protect biodiversity, which in turn protects human health. Amongst other benefits, biodiversity increases dietary nutrients, protects humans from infectious diseases, and improves mental health and well-being. Land clearance can push animal populations out of their natural habitats and into closer contact with human populations, risking the spread of zoonotic diseases such as Dengue, Nipah, Hendra, Ebola and Leishmaniasis.<sup>69</sup> Land is also often cleared to make way for cropland by burning forests. Globally, forest clearance accounted for 9% of all human-produced greenhouse gas emissions from 1959–2011.<sup>70</sup>



Though forest cover across the globe reduced dramatically in the 20th century, the past 25 years have seen some positive developments. The net rate of forest loss dropped from an annual net loss of 0.18% in the 1990s to 0.08% in the period 2010–15, according to the FAO, and sustainable forest management has increased. Planted forest area increased by 105 million hectares between 1990 and 2015, though there was a net forest loss of 129 million hectares overall, and carbon stocks in forest biomass decreased by almost 11 Gt, mainly driven by land use changes. Nonetheless, while the past quarter century has seen real progress, important challenges remain.

### 3.4 Energy Use

The rise of agriculture and cities has led to a dramatic increase in energy use. Since mastery of fire enabled humans to cook, survive in less hospitable habitats, and develop early tools,<sup>71</sup> the main source of energy used has changed from renewable biomass (mainly wood), through water-powered early mills and steam power, to non-renewable fossil fuels including coal, oil, and gas – used directly or via electricity networks. Pre-industrial revolution, most of the world's fuel came from wood, but from the early 19th century onwards an increasing amount came from coal, which provides more energy per kilogramme burned, but which cannot be replaced. In the early 20th century, oil and natural gas, which are also more efficient sources of fuel, began to replace coal as the world's principal source of energy.

A dramatic increase in energy use took place through the shift from renewable biomass to non-renewable fossil fuels. The key difference between the fuels is that burning fossil fuels releases the carbon stored underground into the atmosphere as carbon dioxide, whereas biomass is already part of the active climate system. CO<sub>2</sub> is a

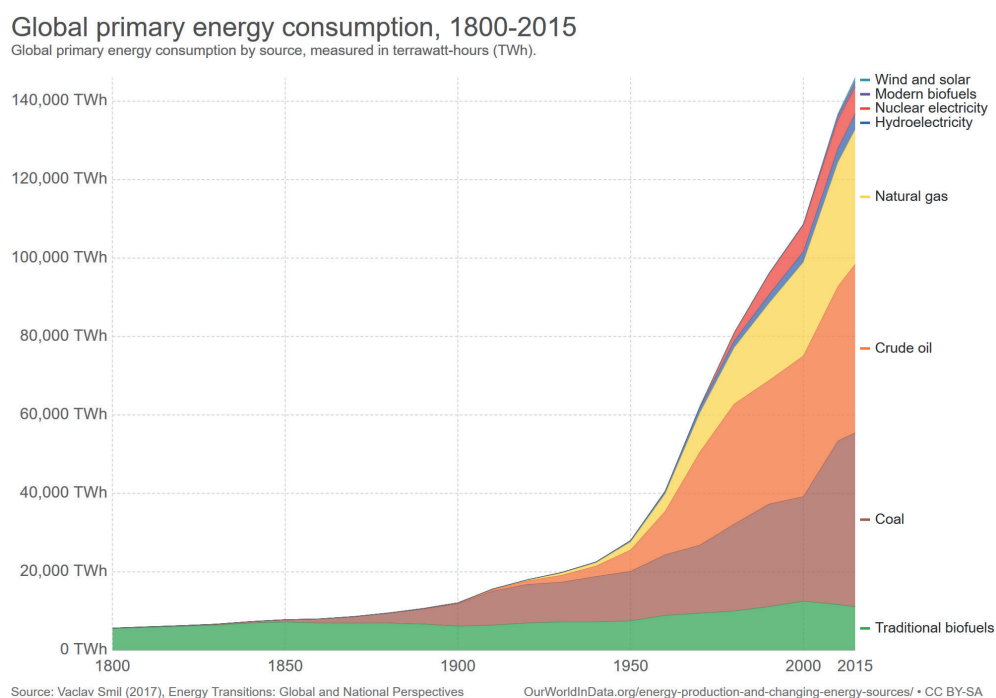


Figure 10: Global primary energy consumption, 1800–2015. (Source: Our World in Data)

greenhouse gas (GHG), so it traps heat in the atmosphere that would otherwise radiate out into space, thus warming the climate. It can take thousands of years for carbon to be removed from the active climate system again. The excess carbon dioxide in the atmosphere has driven global warming and ocean acidification (it dissolves in the oceans to form carbonic acid) since the industrial revolution. Burning fossil fuels also releases other pollutants into the air, including SO<sub>2</sub> (sulphur dioxide, which also causes ocean acidification), nitrogen oxide (an irritant, which together with SO<sub>2</sub> causes acid rain), mercury and particulate matter – small particles of soot, smoke, and other chemicals which can be absorbed into the bloodstream through the lungs. Energy

use is closely tied to urbanization: cities require more energy than rural areas to fuel the industries they support and for domestic use including heating and cooling, cooking and refrigeration, lighting, transport, and entertainment. Chinese urban residents use nearly 1.6 times as much commercial energy as rural residents.<sup>72</sup> The indirect energy impact of cities (i.e. energy used to supply goods and services to city dwellers) can increase energy use by a factor of three.<sup>73</sup> The amount of energy used, and its source, has a significant impact on global environmental change.

**Chinese urban residents use nearly 1.6 times as much commercial energy as rural residents. Energy used to supply goods and services to city dwellers can increase this by a factor of three.**

As with most of the Great Acceleration trends, total global energy use rises with population. Per capita energy consumption also rises with GDP. It currently stands at less than 5 gigajoules per person per year in low-income countries such as Afghanistan, but rises to more than 1000 gigajoules in high-income economies such as Qatar. Over the past 200 years, the amount of energy the world has used has steadily increased, with a six-fold increase in energy use between 1950 and the present day. This is predicted to rise by 50% by 2030.<sup>74</sup>

### Relationship Between GDP and Energy Use

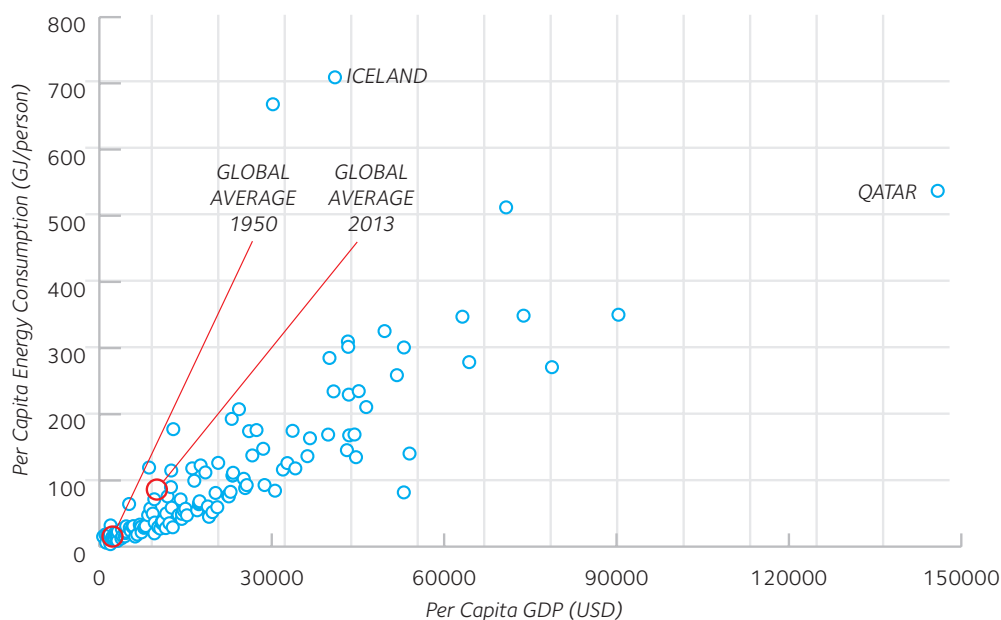


Figure 11: Energy use per person per year as a function of per capita GDP. Residents of countries with higher GDP use more energy per person than residents of lower-income economies. (Source: World Data Bank)

Greenhouse gas emissions from energy use are the main driver of rising temperatures and this represents a dilemma to planetary health: energy is needed to heat homes in cold countries, to cool them in hot ones, to keep food frozen and free of bacteria, and to power sewage systems and water treatment works. Essential infrastructure such as hospital equipment needs to be kept running and transport systems need to deliver food from farms to supermarkets, and commuters to their places of work. Energy is needed to maintain the quality of life on which good health depends, but more renewable and cleaner ways of producing it are needed.

## 4.0 Human Health and the Environment

### 4.1 Human Health Impacts of Global Environmental Change



The previous sections have set out how human health has changed with human progress, and how different environments have been altered by that progress. This section will focus on some of the main pathways through which global environmental change has impacted human health directly and indirectly. These health impacts are not always straightforward, however, nor are they immediate. Environmental factors create complex health outcomes, with negative impacts needing to be weighed against more positive ones. For example, pollution from the use of energy to power stoves and refrigerators needs to be weighed against food poisoning from uncooked or spoiled food.

The key question for the 21st century is whether the balance between the environment and health has tipped, with an overall deficit to health. The Lancet Commission on Health and Climate Change concluded in 2015 that climate change “threatens to undermine the past 50 years of gains in public health, and conversely, that a comprehensive response could be the greatest global health opportunity of the 21st century”.<sup>75</sup>

This section focuses not only on climate change, which leads to increased surface temperatures, heat stress, natural disasters, and ocean acidification, but also on biodiversity loss – caused by the destruction of natural habitats for urban centres and agricultural land – and pollution – the release of toxic materials into the environment. It sets out a number of pathways through which environmental degradation can negatively impact on human health.

This does not, however, mean that such environmental changes are inevitable, nor that the impact they have on health cannot be offset or mitigated. When damaging change is recognized, environmental legislation can be put in place to protect the environment and the health of the people who live in it. Examples of this include the creation of the US Environmental Protection Agency and the subsequent Clean Air Act 1970 and Clean Water Act 1972. The Clean Air Act saw a 70% drop in the aggregate emissions of six common air pollutants between 1970 and 2015<sup>76</sup>. The UK Public Health Act 1891, which regulated industrial emissions, and the Clean Air Act 1956, which stipulated that only smokeless fuels should be burned within towns and cities have had a similar impact, with levels of suspended particulate matter (spm) dropping from around 200µg m<sup>-3</sup> in the 1950s to 16µg m<sup>-3</sup> in 2016. In developing nations – particularly the BRICs – where regulation and compliance may be weak, pollution levels mirror those seen in the 1920s and 30s in London and New York. In India, this has been blamed on several factors including poor implementation and compliance of regulation and inadequate monitoring<sup>77</sup>. Regulation and environmental protection at a national level has seen marked improvements in air quality in developed nations.

## The Ozone Layer and the Montreal Protocol: A Success Story for Planetary Health Action

An excellent example of an early recognition of global environmental change and its impact on human health is the story of the Montreal Protocol. The ozone layer is a part of the Earth's stratosphere; ozone is a gas that shields the Earth's surface from the sun's potentially harmful ultraviolet rays. Since the 1950s, emissions of first, CFCs (chlorofluorocarbons) and later HCFCs (hydrochlorofluorocarbons) released into the atmosphere from refrigerators, aerosol cans, solvents, and air conditioners depleted the ozone layer, enabling more UV radiation to reach the Earth. This resulted in an increase in skin cancers and cataracts.

In recognition that something had to be done, the 1987 Montreal Protocol placed controls on the use of ozone depleting substances (ODS), along with incentives for investment in less-damaging alternatives, and aims to see CFCs phased out completely by 2040. This has resulted in 2 million fewer skin cancers per year globally (14% reduction)<sup>78</sup> and an estimated 22 million fewer cataract cases in the US for Americans born between 1985 and 2100<sup>79</sup> compared with scenarios in which ODS use would have continued at pre-treaty levels.

Adherence to the Montreal Protocol has reduced the amount of ozone depleting substances in the atmosphere, and is predicted to result in a return to pre-1980 ozone levels by mid-century. However, even with swift action, the ozone hole is only now showing the first tentative signs of recovering.<sup>80</sup> Other anthropogenic emissions, of nitrous oxide and other halogenated gases in the tropics in particular, can also destroy stratospheric ozone, so there is concern that these emissions may slow the recovery of the ozone hole.<sup>81</sup>

There is a climate co-benefit of reducing ozone depleting substances, as they act as greenhouse gases. However, if the current mix of HFCs (hydrofluorocarbons) that are used as replacement gases remains the same, projections for demand show that the climate gains would be reversed. For this reason, the Kigali Agreement<sup>82</sup> agreed to limit HFCs in a bid to avoid 0.5°C of warming by the end of this century.

This shows that global environmental change can be reversed if identified early enough, and with sufficient political incentive for concerted action at the international level. However, progress and policies must continuously be evaluated (as the Montreal Protocol is) to ensure the positive consequences of actions outweigh the negative.

## 4.2 Climate Change: Health and Greenhouse Gases

The Earth's atmosphere is warming due to the burning of fossil fuels, land use change, and agriculture, which increases the amount of greenhouse gases in the atmosphere. The main driver is CO<sub>2</sub>, followed by methane, nitrous oxide and halocarbons (which include CFCs and their replacements). Tropospheric ozone is a secondary pollutant that can be produced downwind of pollution sources, following reactions between nitrogen oxides (e.g. from burning sources, or soils) and volatile organic compounds. Tropospheric ozone is not only a greenhouse gas, but at high concentrations is also a lung irritant and detrimental to crops.

Greenhouse gases are causing the temperature of land surfaces, air, and oceans to rise, and ocean acidification to increase<sup>83</sup> with direct impacts on human health. For instance, high-end estimates predict as many as 38,000 people could die from direct effects of heat exposure each year between 2030 and 2050, with up to 251,000 dying from indirect effects of just three diseases (increased incidence of malaria, diarrhoeal disease, and under-nutrition),<sup>84</sup> mostly

in sub-Saharan Africa and Asia where temperatures will be highest. Hospital admissions for respiratory conditions, which already contribute to more than 3 million deaths a year worldwide, show marked increases on hotter days in many regions of the world<sup>85,86</sup> and this has been linked to increased air pollution. Levels of sulphur dioxide, ozone, nitrogen dioxide and particulate matter are all made worse by excessive heat.<sup>87,88</sup>

### Increased world temperatures

The mean surface temperature of the Earth has increased since 1800. Since the 1970s, the rate of increase has been about 0.2°C per decade, and projections are that global temperatures could increase to between 2.6°C and 4.8°C (above pre-industrial levels) by the end of the 21st century. The most recent UNEP Emissions Gap Report predicts a temperature increase of 3.2°C by 2100<sup>89</sup>, even if the National Determined Contributions of the Paris Agreement are fully implemented. Even the lower-end estimates will have a significant impact on some parts of the world. The effects of increased surface temperatures vary, based on local climatic conditions and the extent of urbanization. Global warming is more pronounced over land than sea, and more pronounced in urban areas than rural ones<sup>90</sup> due to synthetic surfaces such as asphalt and concrete that retain more heat – especially at night, when humans need to cool down in order to remain healthy – than natural ground cover. Lack of shade and density of polluting traffic also impact urban temperatures. People living in such urban “heat islands”,<sup>91,92</sup> which can be 10°C hotter than surrounding areas, are at greater risk of ill health during extreme heat events.<sup>93,94</sup>

### Increased temperature and heat stress

Heat exhaustion occurs when body temperature rises above the level at which it is usually maintained – the normal average is 37°C – through a process called thermo-regulation. If it rises above 38°C, a person experiences a state of heat stress; they may feel dizzy, tired, weak, or nauseous, and develop a headache or thirst. If their temperature rises above 40°C, there is a risk of organ failure and loss of consciousness. At such temperatures, death can occur after only 30 minutes.<sup>95</sup>

When the ambient temperature of the environment is lower than that of the human body, heat can be naturally dissipated to the surrounding air should it rise during, for instance, physical exercise or manual labour. The hotter and more humid the environment, the more difficult this process becomes. Temperatures above 26°C pose a moderate to high risk of heat stress symptoms and temperatures of 34°C or above pose a severe risk.<sup>96</sup> Chronic diseases such as diabetes and heart disease magnify individual risk,<sup>97,98</sup> as do factors such as age – infants and the elderly are both disproportionately affected, and risk increases sharply above 50 years of age.<sup>99</sup>

As global average surface temperatures increase, more regions of the world are experiencing regular summer temperatures in the moderate to high risk bracket (26–33°C) for heat stress. Climate change has at least quadrupled the risk of extreme summer heat events in Europe.<sup>100</sup> For example, in June 2017, local records were

### Drivers of temperature rise

Global atmospheric CO<sub>2</sub> increased from pre-industrial levels of 280ppm to above 400ppm in 2016.<sup>177</sup>

This exceeds by far the natural range (180–300ppm) over the past 650,000 years.

Levels increased more rapidly between 1995–2005 than over the previous 40 years.

Global atmospheric levels of methane and nitrous oxide have also increased.

These greenhouse gases absorb and trap heat, leading to increased temperatures.

broken in the Netherlands, Portugal, and Spain, where the average temperature was 4°C hotter than usual in July. Afternoon temperatures above 40°C, often alongside night-time temperatures above 30°C, were experienced in Corsica, Italy, and Croatia. In the 1900s, a similar heatwave would have been extremely rare<sup>101</sup> but by the middle of the 21st century this could rank as a normal summer average.<sup>102</sup> The chance of a severe summer heatwave like those experienced in 2003 and 2017, happening again in Europe in any given year, is predicted to be 12% at current world temperatures, rising to 25% should the global temperature rise reach 1.5°C, and to 42% with a 2.0°C temperature rise.

Around 125 million additional people aged over 65 are estimated to have been exposed to heatwaves annually between 2000–2016 due to a combination of climate variation and demographic change.<sup>103</sup> More than 15% heat-related excess mortality is predicted towards the end of the 21st century in Southern Europe, South America and South-East Asia (with no data available for Africa) under the highest emission scenarios.<sup>104</sup>

As poor urban planning, poor building design, and lack of air conditioning can magnify the impact of higher temperatures, rapid and poorly planned urbanization may lead to negative health outcomes<sup>105</sup>, particularly in the low-income economies of sub-Saharan Africa and South-East Asia.<sup>106</sup> A similar problem may be faced in Southern Europe, where most buildings have not been designed with heat dissipation in mind. Before access to electricity was widespread, buildings in hot climates were designed to keep inhabitants cool through architectural features alone, but modern buildings rely more on air-conditioning.

There is a strong positive correlation between increased heat and increased mortality and morbidity.<sup>107,108,109</sup> Daily mortality rates in many areas of Japan have been shown to rise as temperatures surpass 28°C.<sup>110</sup> The 2003 heatwave in Europe caused 14,802 excess deaths in France alone.<sup>111,112</sup> Italian hospitals saw a 15% spike in hospital admissions during the 2017 heatwave.<sup>113</sup> In Wuhan, China, air pollution-related deaths were shown to be higher on hotter days. In New York, daily mortality spiked after a city-wide power failure in August 2003 that caused air conditioning to fail.<sup>114</sup>

In addition to the direct health effects of higher temperatures, there are various indirect health effects. The disease burden caused by salmonella food poisoning in Australia could double by 2030 if temperature increases by 1.5°C.<sup>115</sup> Increasing temperatures threaten to increase the spread of several vector-borne diseases including malaria, dengue, Lyme disease and encephalitis.<sup>116</sup> Deaths and injuries caused by forest fires were reported in Albania, Serbia, Macedonia, Greece and Italy during the 2017 summer heatwave; 60 people are reported to have died in forest fires in Portugal alone.<sup>117</sup>

### Heatwave impacts

14,802 excess deaths  
(France, 2003)

15% spike in hospital  
admissions (Italy, 2017)

60 people killed in  
forest fires (Portugal,  
2017)

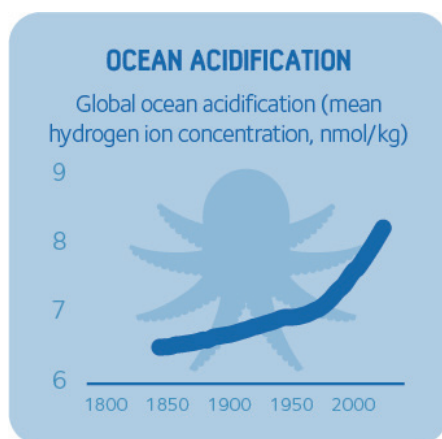
Cases of food  
poisoning in Australia  
could double by 2030

Afternoon temperatures  
above 40° may  
become common in  
Europe by 2050

## 4.3 Climate Change: Extreme Events and Ecosystem Disruptions

Droughts and famines have long affected Africa, but may become more common in other regions of the world, too. A projected increase in weather-related disasters driven by climate change could affect two-thirds of the European population – around 350 million people – annually by the year 2100, compared with just 5% – 25 million people – between 1981 and 2010, with 50 times more fatalities.

Food shortages may also increase in previously temperate climates as well as the areas of sub-Saharan Africa that have long been prone to drought and famine. Half of Bosnia's agricultural output was affected during the 2017 European heatwave, resulting in a 10% reduction in economic output. The Italian agriculture sector anticipated a loss of billions of dollars. At a global mean warming level of 2°C, a third of the total land surface could be arid<sup>118</sup>, although this could be avoided in two-thirds of these regions if warming is limited to 1.5°C.



### Health impacts of ocean acidification and warming

Increased levels of atmospheric CO<sub>2</sub> in recent years have led to changes in the chemical composition of the oceans, dropping their natural alkalinity by 0.1 pH since the beginning of the Industrial Revolution. This amounts to a 26% change in ocean acidity, which is predicted to increase by 170% by 2100.<sup>119</sup> This causes damage to marine life, including many species that are an important food source for many communities. Coral reefs that provide habitat for marine species, and dissipate wave energy to protect coastal communities from flooding, are particularly affected. The full impacts of ocean acidification are not yet entirely known, but they represent another large-scale environmental change at the global level.

Sea levels rose at a rate of 2.8 to 3.6 mm per year between 1993 and 2010<sup>120</sup>, from melting of land ice and from the expansion of water as it heats up. As many as 1.4 billion people could be living in low lying coastal zones by 2060, which will be at risk of flooding due to sea level rises. A large proportion of these people will be in Asia – which has the highest area of land mass at risk of flooding – and in Africa, where significant urban growth is taking place in coastal regions.<sup>121</sup>

### Food systems and nutrient balance

Higher CO<sub>2</sub> levels significantly reduce essential nutrients such as protein, zinc, and iron in crops including rice, maize, and soybean.

**Wheat grown under high levels of CO<sub>2</sub> can contain 9% less zinc, 5% less iron and 6% less protein; rice can contain 8% less protein and 3-5% less iron and zinc. Zinc content in wheat could drop by nearly 10% by 2050.**

A reduction of these nutrients may lead to nutrient deficiency, particularly in babies and pregnant women. Around 2.4 billion people globally get 60% of their zinc and iron from these plants, and in countries including Bangladesh and Armenia, it can be over 75%.<sup>122</sup> If levels of CO<sub>2</sub> in the atmosphere rise as predicted by 2050, this could put an additional

25 million more children at risk of malnutrition from failing crops, higher food prices and poorer quality food.<sup>123</sup> As the loss of protein content sometimes leads to increased carbohydrate concentration in certain foods, the change could lead to higher rates of diabetes, heart disease, and stroke. Eating a greater volume of food to receive the same quantity of nutrients is not a feasible option, though breeding strains that are less susceptible to rising CO<sub>2</sub> levels might be.

Temperature rise also affects food security. As many as 530,000 global annual deaths have been projected due to the impacts of climate change on crop yield by the middle of the 21st century, leading to reductions in fruit and vegetable consumption.<sup>124</sup> Droughts and flooding due to climate change, for instance, cause crop failure<sup>125</sup> and diminish the quality of the crops that do grow. Per capita freshwater availability has declined by 75% in the Arab world over recent decades, which significantly threatens food security.

Salinization of freshwater, caused by inefficient agricultural irrigation, withdrawal of seawater due to temperature rise, and low annual rainfall in coastal regions, is a further problem. In Bangladesh, salinization of freshwater systems in coastal areas has been linked to increased risk of high blood pressure in pregnant and non-pregnant adults.<sup>126</sup>

## 4.4 Biodiversity Loss: Health and Less Diverse Ecosystems

Biodiversity loss is a second environmental change that impacts human health. It is driven by unsustainable fishing and hunting practices that deplete natural populations, intensive agriculture, and synthetic urban environments. These drivers impact our diet, mental and physical health.

The Earth has a “living surface” of plant and animal life on land, in the sea and in the air, which is referred to as the biosphere. Within the biosphere are ecosystems or habitats (e.g. a pond, a forest, or a city), in which the living plants and animals coexist. The biosphere is subdivided into biomes – types of environments that share similar characteristics, for instance Lake Michigan in the US and Lake Victoria in Africa each have their own distinct ecosystem but share aquatic freshwater biome characteristics that influence the plants and animals within them. The human body is itself a microbiome, consisting of human cells and microorganisms, such as bacteria in the gut that influence nutrition and regulate our immune system. As humans live within the wider ecosystems of farmland or urban areas, they themselves represent a unique ecosystem, with trillions of microbes living on and within them. The plants and animals encountered within different ecosystems provide essential dietary nutrients through food, ingredients for medicinal compounds, natural fibres for clothes and materials to build shelter.

Biodiversity refers to the number, variety, and genetic diversity of plant and animal life that coexists within an ecosystem. A high level of biodiversity builds the foundation for a strong and properly functioning ecosystem. This in turn influences air quality, water purity, soil fertility, fish stocks, and Earth’s surface temperature.<sup>127</sup> Different biomes have different levels of biodiversity: moist tropical forests have the highest rates and high-altitude land the lowest. Land that has been cultivated for intensive agriculture, and urban environments, tends to have less biodiversity than natural habitats.<sup>128,129,130</sup>

Biodiversity loss has several, often inter-related impacts on human health. It threatens food systems by impacting food security and reducing the biodiversity of the human diet, making us more vulnerable to the absence of essential nutrients. It heightens plants' vulnerability to infectious disease, risking the loss of entire harvests, and threatens the loss of existing and future natural medicines. Deforestation pushes animals out of their natural habitats and into closer contact with human populations, spreading familiar diseases such as malaria and dengue fever and introducing new ones such as HIV and Ebola. In urban settings, the lack of contact with the natural world during infancy may prevent one's immune system from developing properly.

There is also considerable evidence that biodiversity loss – particularly the loss of mangroves and wetland environments – makes populations more susceptible to natural disasters such as coastal flooding<sup>131</sup> and hurricanes<sup>132</sup>. Decreased marine biodiversity impacts food systems, while rich soils offer protection against diarrhoeal disease in areas where open defaecation is common.

### Land use and biodiversity loss

Biodiversity in the Earth's biosphere, biomes, and ecosystems has been negatively impacted by agriculture, urbanization, and the heavy reliance on non-renewable fuels. Globally, the Earth has lost 52% of its biodiversity between 1970 and 2010, including more than three quarters of freshwater wildlife, 39% of terrestrial wildlife and 39% of marine wildlife.<sup>133</sup> An estimated 42% of mammal species in Europe have been lost; 15% of bird species and 52% of freshwater fish are threatened with extinction.<sup>134</sup>

**Land that has been cultivated for intensive agriculture tends to have less biodiversity than natural habitats, as do urban environments.**

The Earth has lost an estimated 80% of the forest cover it had 8,000 years ago; forests house about half of all biodiversity. More than half of the Earth's biosphere has lost more than 10% of its native plant species and in general habitats are becoming homogeneous across the globe.<sup>135</sup> Alien and invasive species of plants and animals, transferred from one habitat to another either deliberately or accidentally, can also be problematic. Weeds degrade land and water. Agricultural pests reduce crop and livestock productivity, and can outcompete native species to dominate the ecosystem.

### Intensive agriculture and monoculture

In 2014, agricultural land accounted for more than 37.5% of the Earth's terrestrial land surface.<sup>136</sup> Cultivated lands provide a more stable supply of grains, fruit and vegetables and can significantly improve crop yield. While this may be essential to enable the feeding of a growing population with changing dietary habits,<sup>137</sup> intensive agriculture leads to homogenization or monoculture – a situation where a single, often human-adapted crop, is grown over a large area. This reduces native biodiversity, challenging both food security and food quality.<sup>138</sup>



Over the past 50 years, there has been a marked decline in both the number of crop species commonly grown and the genetic diversity within species.<sup>139</sup> There are more than 300,000 known edible plant species, of which around 7,000 are known to have been used by humans at one time or another throughout history,<sup>140,141</sup> but only around 200 are eaten today.<sup>142,143,144</sup> Just 30 crop species provide 90% of the energy consumed by humans<sup>145</sup> and half of all plant-sourced protein comes from three crops: wheat, maize, and rice. Five species of livestock (chickens, cattle, ducks, sheep, and pigs) – provide 95% of animal-derived food.<sup>146</sup> Intensive livestock rearing also drives antibiotic resistance through overuse of antibiotics to promote growth and prevent infection.

### **Dietary diversity across different countries declined by 68% between 1961 and 2009, with diets becoming more homogenized.**

Dietary diversity across countries declined by 68% between 1961 and 2009, with diets becoming more homogenized. Wheat is a staple in over 97% of countries, while other historic staples are declining, including rye (by 45% worldwide), sorghum (by 52%), and millet (by 45%). Declines can also be observed within countries: India had more than 100,000 varieties of rice a century ago, but now has only a few thousand; the US once had 5,000 varieties of apple, but this has dropped to only a few hundred. The biodiversity of our dietary intake is declining considerably.

Monoculture, particularly where there is little in-species genetic diversity, can lead to severe food shortages as it heightens the risk of an entire crop being affected by disease. Lack of genetic diversity in Irish potato crops was a factor in the potato famine of 1845, caused by *Phytophthora infestans*, which resulted in around one million people dying of starvation and a further million migrating.<sup>147</sup> Lack of diversity was also a factor in the decline of the Gros Michael variety of banana as a popular commercial crop after several plantations were wiped out by Panama disease in the 1950s.<sup>148</sup> Cultivated crops, which have little in-species genetic diversity, are often cross-bred with wild relatives or older, non-commercial varieties to improve resistance to disease. If these other varieties become extinct, the ability to protect crops from future outbreaks may be diminished or lost.

### **Dietary diversity and food security**

A diverse food supply delivers a mix of macronutrients such as carbohydrates, proteins and fats, and micronutrients such as vitamins and minerals.<sup>149</sup> Nutrient content can differ significantly across different varieties of plants or breeds of animals. For instance, the consumption of 200g of rice per day can represent anywhere between less than 25% of the recommended daily intake (RDI) of protein or more than 60%, depending on the variety consumed.<sup>150</sup> While one apricot variety can provide less than 1% of the RDI of vitamin A, which protects against eye conditions and respiratory infections, another can provide more than 200%.<sup>151</sup> A healthy human diet is composed of hundreds of beneficial bioactive compounds, and a varied diet is the only way to ensure adequate intake. The Diet Diversity Score (DDS)<sup>152</sup> demonstrates that individuals with more diverse diets tend to have fewer digestive problems, vitamin and mineral deficiencies, lower incidence of stomach cancer, stronger immune systems, and lower mortality in general,<sup>153</sup> but diversity has declined in favour of a narrow range of staple foods. Combined with the challenge of nutrient content declining with temperature changes, this threatens human health.

### Plant-derived medicines

Plants are not only a food source; they are also a source of medicines. More than 70,000 different plants worldwide are used in traditional and modern medicine<sup>154</sup> and half of the 100 most prescribed drugs in the US originate in wild plant species. Plant-derived drugs include the stimulant ephedrine, from *Ephedra sinica* (also known as Ma Huang), used to treat low blood pressure, asthma, and narcolepsy; the anti-malaria drugs quinine, from the cinchona tree, *Cinchona ledgeriana* and Artemisinin, also known as quinghaosu, from *Artemisia annua*;<sup>155</sup> and Salicin from *Salix Alba* which can be used for pain relief, to bring down body temperature and as an anti-inflammatory drug. Ginseng (*Panax quinquefolius*) has properties that can ease the side-effects of cancer treatment,<sup>156</sup> while Asian maypole (*Podophyllum hexandrum*) and the Western yew (*Taxus brevifolia*) are also important for the treatment of cancer.<sup>157</sup> Only a fraction of the world's plant species has currently been investigated for pharmacological potential – their loss may limit the development of new pharmaceuticals in future.<sup>158</sup>

Biodiversity loss also impacts health through disturbed and degraded habitats that mediate exposure to disease. As humans encroach on natural habitats, they come into closer contact with animal and insect vectors.<sup>159,160</sup> Forest fragmentation and land use change have been linked to Ebola outbreaks in Africa<sup>161</sup>, for example, and can be exacerbated by road networks created for logging operations also enabling people to travel further and spread the disease.

## 4.5 Biodiversity Loss: Health and Urban Environments

Urban environments are characterized not only by natural habitat loss, but also by lower species diversity than rural environments. In general, urban areas have fewer species of spiders and birds than forests or even some deserts, for example,<sup>162</sup> though recent research has suggested that urban environments can have high levels of biodiversity.<sup>163</sup> Exposure to biodiversity can be important for the proper functioning of the human microbiome.

Micro-organisms that have been virtually eliminated from home environments may play an important role in the development of the human immune system, particularly in urban environments where children have little contact with animals or nature.<sup>164,165,166</sup> The relationship between humans and the modern environment is receiving increasing attention and was explored recently in *The Lancet* series on evolutionary health.<sup>167</sup> Microbial diversity encountered in today's urban environments comes mostly from exposure to soil, animals, and plants in urban parks, and by keeping pets within the home.<sup>168</sup>

### Diet homogenization

300,000 edible plant species  
7,000 have been used by humans  
Only 200 eaten today

30 crop species provide 90% of energy consumed by humans

**Half of all plant-sourced protein comes from three crops: wheat, maize, and rice**

### Pollinator loss

Pollination is required for 87 leading food crops and 35% of annual food production<sup>124</sup>. In South Asia, 50% of plant-derived Vitamin A is dependent on pollinated crops, and globally, so is 12–15% of iron and folate dependence.

A 50% loss of pollinators is estimated to increase deaths by 0.7 million annually. Pollinator loss is both a result of, and driver of, biodiversity loss. The use of neonicotinoid insecticides is a serious concern to planetary health because they are toxic to bees.

## Well-being and mental health

A key factor in human health may not be the biodiversity of the environment per se, however, but rather how humans interact with it and how easily they are able to access diverse environments. Green space (parks and gardens) and blue space (streams, water features, lakes and fountains)<sup>169,170</sup> are associated with positive mental health benefits and overall well-being, including stress reduction and neighbourhood social cohesion.<sup>171,172</sup> They also encourage spiritual values and social relations.<sup>173</sup>

There is growing evidence that access to green space brings long-term health benefits, including greater longevity, reduced cardiovascular disease, and better mental health. Within urban environments, such spaces can be particularly beneficial for individuals of low socio-economic status<sup>174</sup>, possibly because higher-income individuals are more likely to regularly leave the urban environment and interact with nature on countryside holidays, or to have garden space and be able to keep pets at home.<sup>175</sup> Green space, plants, and animals are part of the workspace for rural communities but are associated more with leisure activity for urban dwellers.<sup>176</sup>

Mental disorders contribute to a significant portion of the Global Burden of Disease. Depression alone accounts for 4.3% of the total burden, with children in developed countries suffering from what has been called a “nature deficit disorder”<sup>177</sup> in which the lack of interaction with outdoor space contributes to anxiety and stress.<sup>178</sup> The promotion of green and blue spaces within urban settings is increasingly seen as important. There is also strong evidence for the positive effects of contact with wild animals and domesticated pets on human mental and physical health.<sup>179</sup>

### Urban gardens

16% of land coverage  
in Stockholm, Sweden

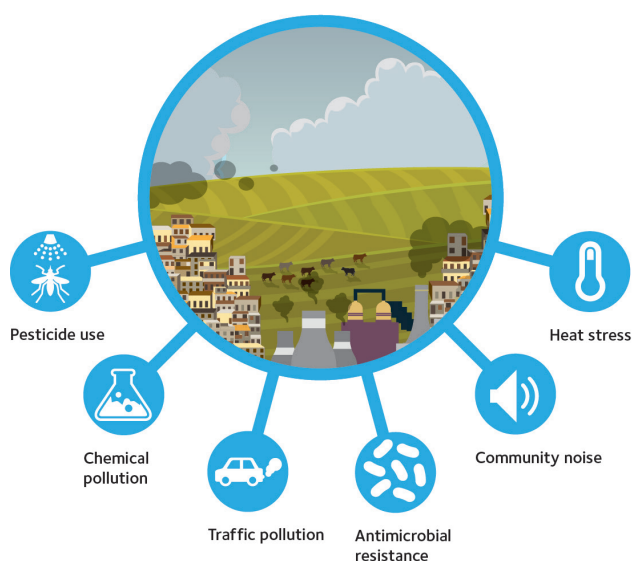
22-27% in UK urban  
areas

36% in urban areas of  
New Zealand

86% in urban areas of  
Leon, Nicaragua

Access to green and  
blue space in cities  
reduces depression  
and several NCDs

## 4.6 Pollution: Environmental Contamination



A third key way in which health and the environment are closely linked is through the impacts of pollution – unwanted, often dangerous materials released into the Earth’s atmosphere by human activity, threatening human health and harming ecosystems.<sup>180</sup> The release of CO<sub>2</sub> and short-lived climate pollutants causes particular problems.

Approximately 9 million<sup>181</sup> premature deaths each year can be attributed to pollution

– this is 16% of all deaths worldwide and is three times more than from AIDS, TB, and malaria combined. The risk of exposure, and the impact of those risks, differs across environments: this section aims to give a brief overview of the key concerns.

Pollution can be grouped into four main categories: air pollution, water pollution, soil pollution, and pollution in the workplace (the exposure to certain pollutants due to a particular profession, such as exposure to fertilizers for agricultural workers or certain chemicals in manufacturing processes).<sup>182</sup> Short-lived climate pollutants such as black carbon, methane, tropospheric ozone and hydrofluorocarbons (HFCs) linked to greenhouse gas emissions also pose direct threats to health.

Pollution can travel across national boundaries, continents, and oceans, impacting health far from where the pollutant was released. An estimated 12% of deaths caused by air pollution occur in a region of the world different to the one in which the pollutant originated: air pollution in China causes deaths in Europe and the US, for example, while it is the market for consumable goods in Europe and the US that has driven the growth of polluting manufacturing industries in China.<sup>183</sup>

This transfer of pollution from regions of the world where raw materials are produced or extracted, to where they are manufactured into tradeable goods and eventually sold, is an increasingly important issue as the world undergoes further development.

In low-income countries with little industrialization, pollution is mostly associated with Group I diseases, particularly with diarrhoeal disease and lower respiratory infections. Drinking water is often contaminated with bacteria such as

### The health impact of pollution

9 million deaths annually attributable to pollution; this is 16% of all deaths worldwide

70% of deaths caused by pollution are NCDs

92% of pollution-related deaths occur in low- and middle-income countries

Air pollution is a causal factor in lower respiratory infections – the only form of infection that appears in the top 20 cause of deaths in high-income countries

*Escherichia coli* and *Salmonella* species, and microscopic parasites including *Cryptosporidium*; rivers and lakes can be contaminated with agricultural fertilizers and industrial chemicals. Lack of tap water, toilets, and sanitation infrastructure are mainly to blame. Worldwide in 2012, diarrhoeal disease was responsible for 57 million DALYs (Disability Adjusted Life Years, a method of calculating how many years of life have been affected by ill-health, disability and early death). Of these, 57% were due to modifiable environmental factors, with 70% of all deaths from water pollution attributable to diarrhoea. Lower respiratory infections were responsible for 51 million DALYs in 2012, of which 35% could have been prevented.<sup>184</sup> Poor regions are also at risk from household air pollution caused by burning wood for cooking and heating homes, and by ambient air pollution caused by land clearance fires. The fine particles emitted by wood burning damage the lungs, increasing susceptibility to respiratory infections and pneumonia, and can lead to cancers and heart disease.<sup>185</sup> Poor air quality also increases the likelihood of low birth weight in babies.<sup>186,187</sup>

Lifestyles in which these conditions are prevalent are falling with declining incidence of extreme poverty worldwide, though 2.3 billion people across the globe still lack access to a basic toilet, 844 million people lack clean drinking water, and 1.2 billion people do not have electricity.

The eradication of poverty alone will not prevent deaths from pollution, since economic development can create its own set of environmental challenges. These can lead to non-communicable diseases, such as cancer, heart disease, and diabetes.

## 4.7 Pollution: Deterioration of Air Quality

The rapid increase in the burning of fuel that comes with industrialization has a significant impact on pollution and health not only due to increased emissions of CO<sub>2</sub> and other short-lived climate pollutants, but also because of the particulate matter released into the air. In total, 85% of particulate matter air pollution is caused by fuel combustion, as is almost all SO<sub>2</sub> pollution, which contributes to acid rain, and nitrogen pollution, which causes respiratory problems and affects plant growth. Coal, used in electricity generation and large-scale manufacturing, is the most polluting fuel and coal mining is also an extremely hazardous occupation. Vehicle fuels are also highly toxic.

Air pollution is linked to 21% of all global deaths from cardiovascular disease, 23% of all stroke-related deaths, 51% of all death from pulmonary disease and 43% of all lung cancer deaths.<sup>188</sup> It is also an aggravating factor in other conditions, including hypertension, premature births and low birthweights,<sup>189</sup> and diabetes.<sup>190</sup> More than 80% of people living in urban areas that monitor air pollution are exposed to air quality levels that do not meet

### Air Pollution

In 2014, 92% of the World's population lived in places where WHO air quality guideline levels were not met

An estimated 6.5 million deaths in 2012 were associated with air pollution.

Air pollution contributed to 21% of global cases of cardiovascular disease in 2015

Air pollution contributed to 23% of stroke deaths in 2015

Air pollution contributed to 43% of deaths from lung cancer in 2015

Caused by vehicle emissions, industrial emissions and landscape clearing fires

(Source: WHO)

WHO guidelines\*, and in low-income cities this rises to 98%. Deaths from air pollution are predicted to increase by more than 50% by 2050.<sup>191</sup>

Deaths related to particulate matter air pollution increased from 3.5 million in 1990 to 4.2 million in 2015, with India and Bangladesh showing particularly sharp increases.<sup>192</sup> However, this is partly due to population growth and a larger number of elderly people who are more susceptible to disease. When such factors are adjusted for, the incidence of deaths from air pollution has in fact declined by 12% worldwide in recent years, due in part to increasing regulation on air quality at national level.

## 4.8 Pollution: Industrialization and Manufacturing

The manufacturing and mining industries can be highly polluting. Product manufacturing (e.g. clothing and toys) and chemical manufacturing (e.g. fertilizers, pesticides, and paints) can release toxic pollutants into the environment. While the health effects of some of the chemicals released by these activities are well known, such as the link between asbestos and lung disease<sup>193</sup>, or chlorofluorocarbons (CFCs) with skin cancers and cataracts due to ozone depletion,<sup>194</sup> others are not. Production is often concentrated in low- and lower-middle income countries where health and environmental protection can be weak. As well as manufacturing plants that are still operational, legacy (i.e. abandoned) and unregulated sites for manufacture, storage, and recycling can pose a specific danger.<sup>195</sup> Products banned in some countries are often still used in lower-income ones, where they may be produced illegally.<sup>196</sup>

Since 1950, more than 140,000 new chemicals and pesticides have been synthesized. Of these, the 5,000 that are produced in the greatest volume have become widely dispersed in the environment. Fewer than half of these have undergone any testing for safety or toxicity. As more are assessed, our understanding of the health burden they impose is likely to rise.<sup>197</sup>

Despite their known health impacts, the use of certain heavy metals, including mercury and chromium, is increasing. Artisanal gold mining is particularly damaging, due to the use of mercury to remove gold from ore<sup>198</sup>, and artisanal tanning, which releases chromium if the process is not carefully controlled. Lead pollution, which can cause heart disease, kidney failure, and stroke in adults and attention deficit disorders, hyperactivity, cognitive impairment, antisocial and criminal behaviour in children and adolescents<sup>199</sup>, is on the rise. Lead production has more than doubled since the 1970s, largely due to the use of lead in mobile phone batteries and cars. In many

### Water pollution worldwide

83% of all water samples worldwide are contaminated

94% of all US water supplies are contaminated

500ml of US tap water contains on average 4.8 microfibres

500ml of European tap water contains, on average, 1.9 microfibres

Contaminants include: Carcinogens, endocrine disrupting chemicals, microplastics and fibres

\* WHO guidelines for clean air are annual average concentrations below  $20 \mu\text{g m}^{-3}$  of particulate matter with diameter less than 10 microns (PM10) and annual average concentrations below  $10 \mu\text{g m}^{-3}$  of particulate matter with diameter less than 2.5 microns (PM2.5); concentrations of Ozone ( $\text{O}_3$ ) below  $100 \mu\text{g m}^{-3}$  over an 8-hour mean; annual average concentrations of Nitrogen dioxide ( $\text{NO}_2$ ) below  $40 \mu\text{g m}^{-3}$  and concentrations of Sulphur dioxide ( $\text{SO}_2$ ) below  $\mu\text{g m}^{-3}$  20 over a 24 hour mean.

low-income countries, lead is still used in pottery glaze, paints and plumbing. An estimated 82% of all deaths from lead pollution occur in low- and middle-income countries, largely due to unsafe practices employed during lead recycling. Better occupational health and safety would remove much of this disease burden. It is also important to note that some recycling activities are themselves highly polluting – the world’s most polluting industry is the recycling of lead-acid batteries used in cars.<sup>200</sup> These batteries can be recycled safely and cleanly in proper recycling facilities, but such facilities are not always available and many used batteries are broken up into their recyclable components by hand. Poorly controlled waste disposal can also cause unnecessary pollution.

### Neurotoxins and endocrine disruptors

Lead is a neurotoxin, which damages the nervous system and can affect brain development and cognitive function. Reducing the mean blood concentration of lead in the US since 1980 has resulted in an increase of 2-5 IQ points across the population.<sup>201</sup>

Many chemicals used in manufacturing have neurotoxic effects, particularly those used in the manufacture of herbicides and pesticides.<sup>202,203</sup> These products can also contain endocrine disrupting chemicals (ECDs), which mimic, block, or alter the actions of normal hormones and may be linked to obesity, diabetes, cardiovascular diseases, male and female reproductive problems, hormone-sensitive cancers such as breast and prostate cancers, thyroid disruption, decreased IQ, and behavioural disorders<sup>204</sup>.

Effects can be particularly strong if encountered during pregnancy. ECDs are present in an estimated 0.5 billion kg of pesticides used annually in the US and nearly 2.5 billion kg used globally. They are also present in flame retardants, soaps, shampoos, plastics and food containers.

A further form of pollution in industrialized nations comes from active pharmaceutical ingredients (APIs) in pharmaceutical waste. The chemicals used to produce anti-inflammatory drugs, antibiotics, the contraceptive pill, and radionuclides from cancer therapy agents are all commonly detected in the environment due to leakages during the manufacturing process, impacting at the point of manufacture, and small amounts in excretion,<sup>205</sup> impacting on the end-users’ local environment.

### Chemical pollution to water supplies

Pollution of water sources by these chemicals affects water ecosystems. Fish and shellfish can be damaged, eliminating them from the food chain.<sup>206</sup> ECDs and neurotoxins concentrate in marine food stocks living in polluted waters, adding to human exposure when they are eaten. Phosphorus from detergents and fertilizer run-off also causes the eutrophication of water bodies – excessive plant growth that suffocates some plant species while promoting excessive growth in others.

Water systems are also increasingly contaminated with microplastics – small plastic particles in the environment: 83% of all water samples worldwide are contaminated, including 94% of all US water supplies. One study found

#### Toxic Contaminants

Lead
Population at risk: 13m
Mercury
Population at risk: 8m
Chromium
Population at risk: 5m
Petrochemical sites
Population at risk: 4m
Radionuclides
Population at risk: 3m
Pesticide manufacturing
Population at risk: 1.2m

an average of 4.8 fibres per 500ml of water in the US and 1.9 in Europe,<sup>207</sup> including HDPE (High Density Polyethylene) which has been linked to breast cancer, can alter sex ratios, is a risk factor for testicular cancer and poor semen quality, can induce early puberty, and can cause reproductive tract malformation. PVC (Polyvinyl Chloride) is an ECD which has been linked to the improper development of reproductive organs in fetuses. BPA (Bisphenol A) has also been linked to hormonal changes, reproductive problems, asthma and obesity. PS (Polystyrene) is considered a human carcinogen.

## 4.9 Pollution and Economic Development

As countries develop, the health challenges they face change with the types of industry on which they rely. While mining and heavy manufacturing began in Europe with the Industrial Revolution<sup>208</sup> and continued until the middle of the 20th century, they have largely moved out of high-income countries into developing ones, creating an uneven geography of pollution that has a disproportionate effect in sub-Saharan Africa and Asia (see Figure 12). Industrial and pharmaceutical pollutants have a more severe effect in regions where water purification plants are not fully developed and are inefficient at removing pollutants. Pollution is therefore worst in rapidly urbanizing countries where infrastructure development lags behind industrial development.<sup>209</sup>

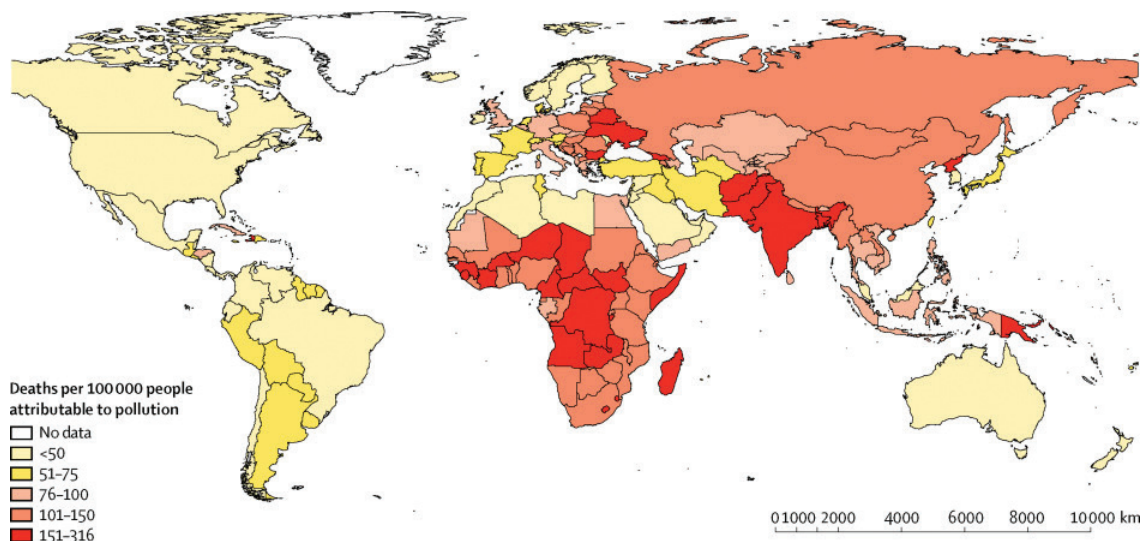


Figure 12: The most polluted areas of the world are those that lag furthest behind in the demographic and epidemiological transitions, and which are lower income economies. Source: Landrigan et al (2017)

An estimated 92% of all pollution-related deaths occur in low- and middle- income countries, with a resulting cost burden: pollution-related diseases account for 1.7% of annual health spending in high-income countries, but 7% in middle-income countries. Part of this is due to the growth of cities in these regions,<sup>210</sup> and the rising energy demands, petrol- and diesel-powered vehicle use, consumerism, and the intensification of agriculture that comes with it, particularly when this is happening faster than protective environmental policy and regulation is put in place.

Approximately 3 million people each year die from exposure to outdoor air pollution and 4.3 million people die from indoor air pollution, mostly caused by wood-burning stoves. More than 50% of all global air pollution deaths occur in just two countries, China and India, even though these account for only 36% of the global population. In developing countries, 98% of urban areas with populations of more than 100,000 fail to meet WHO air quality guidelines.<sup>211</sup> The figure is closer to 50% in high-income urban areas.

A second significant factor in pollution-related deaths, however, is the common accusation that high-income countries deliberately move more polluting industries from their own backyard to lower-income countries with less stringent environmental and occupational protection regimes. An example of this is the US-owned Union Carbide pesticide factory in Bhopal, India, where an explosion caused by a gas leak in 1984 killed 3,787 people and injured more than half a million.

Almost 80% of obsolete electronics delivered to a recycling service in the US will end up in low or lower-middle income countries such as Nigeria, Pakistan, and Vietnam, and low-income areas of China and India for recycling.<sup>212</sup> High-income economies also use lower-income countries as dumping grounds for their unwanted toxic products, including some that are banned or highly regulated under the 1989 Basel Convention, and for the siting of their hazardous and polluting manufacturing industries. For example, toxic waste from Europe shipped to Côte d'Ivoire in 2006 resulted in the release of toxic gas that killed 17 people and caused 100,000 cases of respiratory and gastrointestinal disease.<sup>213</sup> There is also evidence, however, that multinational manufacturing companies employ less polluting processes than local industries and can drive local adherence to international standards.<sup>214</sup>

In high-income economies, pollution is often greatest in poorer areas. In New York, bus depots that emit pollutants which can cause an increase in asthma and other respiratory diseases, are more likely to be in or close to disadvantaged neighbourhoods.<sup>215</sup> Poorer people tend to live in poorer quality environments, exacerbating health problems.

### **Pollution and urbanization**

The regions of the world that are urbanizing most rapidly are also the ones that will be most at risk from climate change, biodiversity loss, and pollution. The countries that will be the most exposed to temperatures above 34°C, the threshold for high-risk

### **The Kuznets curve and the environment: A disputed correlation**

The Kuznets curve, developed by economist Simon Kuznets, describes the association between income inequality and per capita income during economic development. In the early stages of urbanization and industrialization, inequality grows, but the widening gap later closes. This has been extended to postulate that pollution and environmental degradation must also get worse before they get better.

However, most recent research disputes this, and theorizes that it should be possible to achieve modernisation and reach a high-income economy cleanly through clean energy generation, environmental protection legislation, and the avoidance of chemicals that are known to be toxic, capitalizing on lessons learned in Europe, North America and Japan.

heat stress, for example, are in sub-Saharan Africa and South-East Asia. They face an increasingly elderly population, living in the type of urban environments where heat stress, pollution, and low biodiversity are more likely. Air pollution is worse in high temperatures.

The reliance of such economies on manufacturing industries and agricultural production leads to high numbers of workers employed outdoors, undertaking physical labour in extreme heat.<sup>216</sup> In cities, poorly designed urban environments that provide little shade or protection from heat could impact the ability of the workforce to operate during the hottest parts of the day, with repercussions on economic growth and development. A workforce undertaking light work can operate continuously in 31°C heat, but needs to rest half an hour, each hour, when temperatures rise to 32°C. If people are engaged in more strenuous work, required rest time rises to 75%, and heavy duty assignments are not recommended. Heavy labour can only be safely undertaken for sustained periods at temperatures below 26°C.<sup>217</sup> Global labour productivity is already estimated to have declined by around 5% since 2000.<sup>218</sup>

All these health impacts disproportionately affect the under-fives and the elderly, minorities, the marginalized and lower socio-economic groups. Poverty, poor health, and social injustice are deeply inter-twined, and have a circular effect – exposure to pollutants in childhood is associated with lower cognitive function, lower educational attainment, and lower social mobility, trapping those born into polluted environments into a cycle of poverty. Poor families may not be able to afford to live in the cleaner, fresher areas of their city or country.

Cities can be made more liveable and attractive; environmental protection and regulation, properly implemented and monitored, can play a strong role in enabling this. They can be cleaner, with more sustainable and more circular economies, but this must be applied across the globe; it is not enough to clean up one region by moving pollution-generating industries and practices elsewhere.

#### Pollution and income

92% of pollution-related deaths occur in low- and middle-income countries

98% of developing country urban areas with populations of more than 100 000 fail to meet WHO air quality guidelines

80% of obsolete electronics from the US are recycled in low- and middle-income countries

## 5.0 Conclusion

The aim of this reference paper has been to present the latest scientific evidence on the relationship between global environmental change and human health – the health of current and future generations.

Exactly how the environment impacts human health is complicated, particularly at the global level, due to the long timescales involved and the challenge of isolating environmental impact from the many other variables at play. Human life expectancy has risen from 30–40 years prior to the 19th century to a global average of 71 years in 2015, mainly due to higher incomes, a safer and more stable food supply, and improved public health in cities. Medical technology has also played an important part, particularly in the form of antibiotics and vaccines. Human health has nevertheless suffered from pollution and global environmental degradation. Many of the inter-connections have been documented in this paper.

In sum, this paper has sought to demonstrate that while rising incomes and a variety of other factors have led to substantial progress in human health, this progress has been uneven across the globe. If pollution and global environmental change are not seriously tackled, the health of future generations could be undermined.

## Further information

### **Report of the Rockefeller-Lancet Commission on Planetary Health**

Whitmee, Sarah, Andy Haines, Chris Beyrer, Frederick Boltz, Anthony G. Capon, Braulio Ferreira de Souza Dias, Alex Ezeh et al. "Safeguarding human health in the Anthropocene epoch: report of The Rockefeller Foundation–Lancet Commission on planetary health." *The Lancet* 386, no. 10007 (2015): 1973–2028.

### **Preventing Disease through Healthy Environments**

Prüss-Üstün, A., & Neira, M. *Preventing disease through healthy environments: a global assessment of the burden of disease from environmental risks*. World Health Organization (2016).

### **Connecting Global Priorities: Biodiversity and Human Health**

World Health Organization. "Connecting Global Priorities: Biodiversity and Human Health." World Health Organization and Secretariat of the Convention on Biological Diversity, 2015.

### **Health as the Pulse of the New Urban Agenda**

World Health Organization, "Health as the Pulse of the New Urban Agenda", United Nations Conference on Housing and Sustainable Urban Development. World Health Organization (October, 2016).

### **Global Health 2035: A world converging within a generation**

Jamison, Dean T., Lawrence H. Summers, George Alleyne, Kenneth J. Arrow, Seth Berkley, Agnes Binagwaho, Flavia Bustreo et al. "Global health 2035: a world converging within a generation." *The Lancet* 382, no. 9908 (2013): 1898–1955.

### **Lancet Commission on Pollution and Health**

Landrigan, Philip J., Richard Fuller, Nereus JR Acosta, Olusoji Adeyi, Robert Arnold, Abdoulaye Bibi Baldé, Roberto Bertollini et al. "The Lancet Commission on pollution and health." *The Lancet* (2017).

### **Millennium Ecosystem Assessment**

Millennium ecosystem assessment. *Ecosystems and human wellbeing: a framework for assessment* Washington, DC: Island Press (2005).

### **WWF Living Planet Report 2014**

McLellan, Richard, Leena Iyengar, Barney Jeffries, and Nastasja Oerlemans, eds. *Living Planet Report 2014: species and spaces, people and places*. World Wide Fund for Nature, (2014).

# References

- 1 Bono-Lunn, Dillan, Chantal Villeneuve, Nour J. Abdulhay, Matthew Harker, and William Parker. "Policy and regulations in light of the human body as a 'superorganism' containing multiple, intertwined symbiotic relationships." *Clinical Research and Regulatory Affairs* 33, no. 2-4 (2016): 39-48.
- 2 Rook, Graham, Fredrik Bäckhed, Bruce R. Levin, Margaret J. McFall-Ngai, and Angela R. McLean. "Evolution, human-microbe interactions, and life history plasticity." *The Lancet* 390, no. 10093 (2017): 521-530.
- 3 Steffen, Will, Paul J. Crutzen, and John R. McNeill. "The Anthropocene: Are Humans Now Overwhelming the Great Forces of Nature?(2007)." *The Globalization and Environment Reader* (2016): 27.
- 4 Geels, Frank W., Benjamin K. Sovacool, Tim Schwanen, and Steve Sorrell. "The socio-technical dynamics of low-carbon transitions." *Joule* (2017).
- 5 Sovacool, Benjamin K. "How long will it take? Conceptualizing the temporal dynamics of energy transitions." *Energy Research & Social Science* 13 (2016): 202-215.
- 6 Millennium Ecosystem Assessment. "Millennium ecosystem assessment." *Ecosystems and human wellbeing: a framework for assessment* Washington, DC: Island Press (2005).
- 7 Landrigan, Philip J., Richard Fuller, Nereus JR Acosta, Olusoji Adeyi, Robert Arnold, Abdoulaye Bibi Baldé, Roberto Bertollini et al. "The Lancet Commission on pollution and health." *The Lancet* (2017).
- 8 Henderson, Donald Ainslie DA. "Smallpox Eradication: Leadership and Legacy." *The Journal of Infectious Diseases* 215 (2017): 673-6.
- 9 Cochi, S. L., Hegg, L., Kaur, A., Pandak, C., & Jafari, H. (2016). The global polio eradication initiative: Progress, lessons learned, and polio legacy transition planning. *Health Affairs*, 35(2), 277-283.
- 10 World Health Organization. "Life expectancy". Global Health Observatory (GHO) data. (WHO 2015). [http://www.who.int/gho/mortality\\_burden\\_disease/life\\_tables/situation\\_trends/en/](http://www.who.int/gho/mortality_burden_disease/life_tables/situation_trends/en/)
- 11 Whitmee, Sarah, Andy Haines, Chris Beyrer, Frederick Boltz, Anthony G. Capon, Braulio Ferreira de Souza Dias, Alex Ezech et al. "Safeguarding human health in the Anthropocene epoch: report of The Rockefeller Foundation-Lancet Commission on planetary health." *The Lancet* 386, no. 10007 (2015): 1973-2028.
- 12 Haines, Andy. "Addressing challenges to human health in the Anthropocene epoch: an overview of the findings of the Rockefeller/Lancet Commission on Planetary Health." *Public Health Reviews* 37, no. 1 (2016): 14.
- 13 Global Burden of Disease collaborators, "The Global Burden of Disease", *The Lancet*, (2016), <http://www.thelancet.com/gbd>
- 14 Prüss-Üstün, Annette, and M. Neira. "Preventing disease through healthy environments: a global assessment of the burden of disease from environmental risks". World Health Organization, 2016.
- 15 Mathers, Colin. "The global burden of disease: 2004 update". World Health Organization, 2008.
- 16 OECD, "Health at a Glance 2011: OECD Indicators – Health Status – Life Expectancy at Birth", OECD [http://www.oecd-ilibrary.org/sites/health\\_glance-2011-en/01/01/index.html?ns/Chapter&itemId=/content/chapter/health\\_glance-2011-4-en](http://www.oecd-ilibrary.org/sites/health_glance-2011-en/01/01/index.html?ns/Chapter&itemId=/content/chapter/health_glance-2011-4-en)
- 17 Hotez, Peter J., Ashish Damania, and Mohsen Naghavi. "Blue Marble Health and the Global Burden of Disease Study 2013." *PLoS neglected tropical diseases* 10, no. 10 (2016): e0004744.
- 18 Steffen W, Sanderson A, Tyson PD et al. (2004) *Global Change and the Earth System: A Planet Under Pressure*. The IGBP Book Series. Berlin, Heidelberg, New York: Springer-Verlag
- 19 Smith, Kirk R., Alistair Woodward, Diarmid Campbell-Lendrum, Dave D. Chadee, Yasushi Honda, Qiyong Liu, Jane M. Olwoch, Boris Revich, and Rainer Sauerborn. "Human health: impacts, adaptation, and co-benefits." *Climate change* (2014): 709-754.
- 20 Phillips, Derek L. *Well-being in Amsterdam's Golden Age*. Amsterdam University Press, 2008.
- 21 World Bank Data. "Mortality rate, under-5 (per 1,000 live births)." The World Bank Data. Accessed 30 October 2017. [https://data.worldbank.org/indicator/SH.DYN.MORT?year\\_high\\_desc=false](https://data.worldbank.org/indicator/SH.DYN.MORT?year_high_desc=false)
- 22 Arias, Elizabeth, Melonie Heron, and Jiaquan Xu. "United States life tables, 2013." *future* 2 (2017): 3.
- 23 ScotPHO. "Healthy life expectancy: deprivation quintiles", ScotPHO Public Health Information for Scotland, Accessed 30 October 2017. <http://www.scotpho.org.uk/population-dynamics/healthy-life-expectancy/data/deprivation-quintiles>
- 24 Walsh, David, Gerry McCartney, Chik Collins, Martin Taulbut, and G. David Batty. "History, politics and vulnerability: explaining excess mortality in Scotland and Glasgow."

- Glasgow Centre for Population Health Glasgow (2016).
- 25 Kontis, Vasilis, James E. Bennett, Colin D. Mathers, Guangquan Li, Kyle Foreman, and Majid Ezzati. "Future life expectancy in 35 industrialized countries: projections with a Bayesian model ensemble." *The Lancet* 389, no. 10076 (2017): 1323-1335.
  - 26 Caldwell, John C. *Demographic transition theory*. Springer Science & Business Media, 2007.
  - 27 Omran, Abdel R. "The epidemiologic transition." *Milbank Memorial Fund Quarterly* 49, no. 1 (1971): 509-538.
  - 28 Lutz, Wolfgang, Brian C. O'Neill, and Sergei Scherbov. "Europe's population at a turning point." *Science* 299, no. 5615 (2003): 1991-1992.
  - 29 Lutz, Wolfgang, Warren C. Sanderson, and Sergei Scherbov, eds. *The end of world population growth in the 21st century: New challenges for human capital formation and sustainable development*. Earthscan, 2004.
  - 30 Omran, Ibid
  - 31 Omran, Ibid
  - 32 World Health Organization, "Democratic Republic of the Congo: WHO Statistical Profile", WHO Global Health Observatory, 2015.
  - 33 Coghlan, Benjamin, Richard J. Brennan, Pascal Ngoy, David Dofara, Brad Otto, Mark Clements, and Tony Stewart. "Mortality in the Democratic Republic of Congo: a nationwide survey." *The Lancet* 367, no. 9504 (2006): 44-51.
  - 34 World Health Organization (2016), "Global Health Estimates 2015: 20 Leading Causes of Death by Region" Data provided by WHO press office on request
  - 35 Chauhan, Anoop J., and Sebastian L. Johnston. "Air pollution and infection in respiratory illness." *British medical bulletin* 68, no. 1 (2003): 95-112.
  - 36 Rogers, Richard G., and Robert Hackenberg. "Extending epidemiologic transition theory: a new stage." *Social biology* 34, no. 3-4 (1987): 234-243.
  - 37 Pongsiri, Montira J., Joe Roman, Vanessa O. Ezenwa, Tony L. Goldberg, Hillel S. Koren, Stephen C. Newbold, Richard S. Ostfeld, Subhrendu K. Pattanayak, and Daniel J. Salkeld. "Biodiversity loss affects global disease ecology." *Bioscience* 59, no. 11 (2009): 945-954.
  - 38 Dobson A., Campbell, M.S. and Bell, J., "Chapter 4: Fatal Synergisms: Interactions Between Infectious Diseases, Human Population Growth and Loss of Biodiversity" in Grifo, F., & Rosenthal, J. (Eds.). (1997). *Biodiversity and human health*. Island Press.
  - 39 Holmes, Alison H., Luke SP Moore, Arnfinn Sundsfjord, Martin Steinbakk, Sadie Regmi, Abhilasha Karkey, Philippe J. Guerin, and Laura JV Piddock. "Understanding the mechanisms and drivers of antimicrobial resistance." *The Lancet* 387, no. 10014 (2016): 176-187.
  - 40 Rogers, Richard G., and Robert Hackenberg. "Extending epidemiologic transition theory: a new stage." *Social biology* 34, no. 3-4 (1987): 234-243.
  - 41 Baldwin, Richard. "Does sustainability require growth." *The economics of sustainable development* (1995): 51-78.
  - 42 Rees, William, and Mathis Wackernagel. "Urban ecological footprints: why cities cannot be sustainable—and why they are a key to sustainability." *Environmental impact assessment review* 16, no. 4-6 (1996): 223-248.
  - 43 Jacobs, Jane. *The death and life of great American cities*. Vintage, 2016.
  - 44 Wright, David K. "Humans as Agents in the Termination of the African Humid Period." *Frontiers in Earth Science* 5 (2017):4
  - 45 Figures from the World Population Bureau, <http://www.prb.org>, Accessed 1 November 2017
  - 46 Marchal, Virgine, Rob Dellink, Detlef Van Vuuren, Christa Clapp, Jean Chateau, B. Magné, and J. van Vliet. "OECD environmental outlook to 2050." *Organization for Economic Co-operation and Development* (2011).
  - 47 Khanna, N., David Fridley, Lynn Price, Nan Zhou, and Stephanie Ohshita. "Estimating China's Urban Energy Demand and CO2 Emissions: A Bottom-up Modeling Perspective." (2016).
  - 48 Chini, Christopher M., Megan Konar, and Ashlynn S. Stillwell. "Direct and indirect urban water footprints of the United States." *Water Resources Research* 53, no. 1 (2017): 316-327.
  - 49 Global Burden of Disease collaborators, "The Global Burden of Disease", *The Lancet*, (2016), <http://www.thelancet.com/gbd>
  - 50 Klepinger, Linda L. "The evolution of human disease: New findings and problems." *Journal of biosocial science* 12, no. 4 (1980): 481-486.
  - 51 Næss, Petter. "Urban form, sustainability and health: The case of Greater Oslo." *European Planning Studies* 22, no. 7

- (2014): 1524–1543.
- 52 Gouldson, Andy. Colenbrander, Sarah. Sudmant, Andrew, Godfrey, Nick, Millward-Hopkins, Joel, Fanf, Wanli and Zhao, Xiao. "Working Paper: Accelerating Low-Carbon Development in the World's Cities, New Climate Economy. 2015
  - 53 Kearns, Gerry. "The urban penalty and the population history of England." (1988): 213–236.
  - 54 Kearns, Gerry, and Charles WJ Withers, eds. *Urbanising Britain: essays on class and community in the nineteenth century*. Vol. 17. Cambridge University Press, 1991.
  - 55 Reher, David S. "In search of the 'urban penalty': exploring urban and rural mortality patterns in Spain during the demographic transition." *Population, Space and Place* 7, no. 2 (2001): 105–127.
  - 56 Reher, David S. Ibid
  - 57 Stern, Nicholas and Zenghelis, Dimitri, "Cities for Innovation, for Living and for Sustainability: the Next Two Decades are Critical", Unpublished, 2017
  - 58 Rogers, Richard G., and Robert Hackenberg. "Extending epidemiologic transition theory: a new stage." *Social biology* 34, no. 3–4 (1987): 234–243.
  - 59 ScotPHO. "Healthy life expectancy: deprivation quintiles", ScotPHO Public Health Information for Scotland, Accessed 30 October 2017. <http://www.scotpho.org.uk/population-dynamics/healthy-life-expectancy/data/deprivation-quintiles>
  - 60 Geels, Frank W. "The hygienic transition from cesspools to sewer systems (1840–1930): the dynamics of regime transformation." *Research Policy* 35, no. 7 (2006): 1069–1082.
  - 61 Toye, David L. (May 2004). "The Emergence of Complex Societies: A Comparative Approach". *World History Connected*. 11 (2).
  - 62 Wells, Jonathan CK, Randolph M. Nesse, Rebecca Sear, Rufus A. Johnstone, and Stephen C. Stearns. "Evolutionary public health: introducing the concept." *The Lancet* 390, no. 10093 (2017): 500–509.
  - 63 Klein Goldewijk, K., A. Beusen, J. Doelman and E. Stehfest, New anthropogenic land use estimates for the Holocene; HYDE 3.2; source: Our World in Data website.
  - 64 Lal, Rattan. "Managing soils and ecosystems for mitigating anthropogenic carbon emissions and advancing global food security." *Bioscience* 60, no. 9 (2010): 708–721
  - 65 Global Rural-Urban Mapping Project (GRUMP), "Urban Extents Grid, v1, (1995)", NASA Socioeconomic Data and Applications Centre (SEDAC) <http://sedac.ciesin.columbia.edu/data/set/grump-v1-urban-extents>
  - 66 Lawson, Laura. "Agriculture: Sowing the city." *Nature* 540, no. 7634 (2016): 522–524.
  - 67 Whitmee, Sarah, Andy Haines, Chris Beyrer, Frederick Boltz, Anthony G. Capon, Bráulio Ferreira de Souza Dias, Alex Eze et al. "Safeguarding human health in the Anthropocene epoch: report of The Rockefeller Foundation–Lancet Commission on planetary health." *The Lancet* 386, no. 10007 (2015): 1973–2028.
  - 68 Global Forest Watch, Accessed 31 October 2017, <http://www.globalforestwatch.org/>
  - 69 Hotez, Peter J. "Neglected tropical diseases in the Anthropocene: the cases of Zika, Ebola, and other infections." *PLoS neglected tropical diseases* 10, no. 4 (2016): e0004648.
  - 70 Le Quéré, Corinne, Roisin Moriarty, Robbie M. Andrew, Glen Philip Peters, Philippe Ciais, Pierre Friedlingstein, Samantha D. Jones et al. "Global carbon budget 2014." *Earth System Science Data* 7, no. 1 (2015): 47–85.
  - 71 Gowlett, John AJ. "The discovery of fire by humans: a long and convoluted process." *Phil. Trans. R. Soc. B* 371, no. 1696 (2016): 20150164.
  - 72 Khanna, N., David Fridley, Lynn Price, Nan Zhou, and Stephanie Ohshita. "Estimating China's Urban Energy Demand and CO2 Emissions: A Bottom-up Modeling Perspective." (2016).
  - 73 Khanna, Nina, David Fridley, and Lixuan Hong. *Evaluating China's pilot lowcarbon city initiative: national goals and local plans*. No. LBNL-6266E. Ernest Orlando Lawrence Berkeley National Laboratory, Berkeley, CA (US), 2013.
  - 74 Schwab, Klaus. *The fourth industrial revolution*. Crown Business, 2017.
  - 75 Watts, Nick, W. Neil Adger, Paolo Agnolucci, Jason Blackstock, Peter Byass, Wenjia Cai, Sarah Chaytor et al. "Health and climate change: policy responses to protect public health." *The Lancet* 386, no. 10006 (2015): 1861–1914.
  - 76 Environmental Protection Agency, "Benefits and Costs of the Clean Air Act 1990–2020, the Second Prospective Study". Environmental Protection Agency, 2011

- 77 Bhawe, Prashant P., and Nikhil Kulkarni. "Air Pollution and Control Legislation in India." *Journal of The Institution of Engineers (India): Series A* 96, no. 3 (2015): 259-265.
- 78 Chipperfield, Martyn P., S. S. Dhomse, W. Feng, R. L. McKenzie, G. J. M. Velders, and J. A. Pyle. "Quantifying the ozone and ultraviolet benefits already achieved by the Montreal Protocol." *Nature communications* 6 (2015).
- 79 Environmental Effects Assessment Panel. "United Nations Environment Programme, Environmental effects of ozone depletion and its interactions with climate change: Progress report, 2005." *Photochem. Photobiol. Sci* 5 (2006): 13-24.
- 80 WMO (World Meteorological Organization), Scientific Assessment of Ozone Depletion: 2014, World Meteorological Organization, Global Ozone Research and Monitoring Project-Report No. 55, 416 pp., Geneva, Switzerland, 2014.
- 81 Oram, David E., Matthew J. Ashfold, Johannes C. Laube, Lauren J. Gooch, Stephen Humphrey, William T. Sturges, Emma Leedham-Elvidge et al. "A growing threat to the ozone layer from short-lived anthropogenic chlorocarbons." *Atmospheric Chemistry and Physics* 17, no. 19 (2017): 11929-11941.
- 82 UN Treaty Collection. Environment Chapter XXVII. 2.f Amendment to the Montreal Protocol on Substances that Deplete the Ozone Layer. Kigali, 15 October 2016. See: [https://treaties.un.org/pages/ViewDetails.aspx?src=TREATY&mtdsg\\_no=XXVII-2-f&chapter=27&clang=\\_en](https://treaties.un.org/pages/ViewDetails.aspx?src=TREATY&mtdsg_no=XXVII-2-f&chapter=27&clang=_en), last accessed 18 January 2018
- 83 UNEP. "The Emissions Gap Report 2017: A UN Environment Synthesis Report" United Nations Environment Programme, p.p. xvii. Nairobi, 2017
- 84 World Bank Group. "Geographic Hotspots. For World Bank Action on Climate Change and Health". Investing in Climate Change and Health Series. World Bank Group, 2017.
- 85 Tao, Yan, Shengquan Mi, Shuhong Zhou, Shigong Wang, and Xiaoyun Xie. "Air pollution and hospital admissions for respiratory diseases in Lanzhou, China." *Environmental pollution* 185 (2014): 196-201.
- 86 D'Amato, Gennaro, Carlos E. Baena-Cagnani, Lorenzo Cecchi, Isabella Annesi-Maesano, Carlos Nunes, Ignacio Ansotegui, Maria D'Amato, Gennaro Liccardi, Matteo Sofia, and Walter G. Canonica. "Climate change, air pollution and extreme events leading to increasing prevalence of allergic respiratory diseases." *Multidisciplinary respiratory medicine* 8, no. 1 (2013): 12.
- 87 Katsouyanni, K., A. Pantazopoulou, G. Touloumi, I. Tselepidaki, K. Moustris, D. Asimakopoulos, G. Pouloupoulou, and D. Trichopoulos. "Evidence for interaction between air pollution and high temperature in the causation of excess mortality." *Archives of Environmental Health: An International Journal* 48, no. 4 (1993): 235-242
- 88 Qian, Zhengmin, Qingci He, Hung-Mo Lin, Lingli Kong, Dunjin Zhou, Shengwen Liang, Zhichao Zhu et al. "Part 2. Association of daily mortality with ambient air pollution, and effect modification by extremely high temperature in Wuhan, China." Research report (Health Effects Institute) 154 (2010): 91-217.
- 89 UNEP. "The Emissions Gap Report 2017: A UN Environment Synthesis Report" United Nations Environment Programme, Nairobi, 2017
- 90 Emilsson, Tobias, and Åsa Ode Sang. "Impacts of Climate Change on Urban Areas and Nature-Based Solutions for Adaptation." In *Nature-Based Solutions to Climate Change Adaptation in Urban Areas*, pp. 15-27. Springer, Cham, 2017.
- 91 Clarke, John F. "Some effects of the urban structure on heat mortality." *Environmental research* 5, no. 1 (1972): 93-104.
- 92 Taha, Haider. "Urban climates and heat islands: albedo, evapotranspiration, and anthropogenic heat." *Energy and buildings* 25, no. 2 (1997): 99-103.
- 93 Stone, Brian, Jeremy J. Hess, and Howard Frumkin. "Urban form and extreme heat events: are sprawling cities more vulnerable to climate change than compact cities?" *Environmental health perspectives* 118, no. 10
- 94 Uejio, Christopher K., Olga V. Wilhelmi, Jay S. Golden, David M. Mills, Sam P. Gulino, and Jason P. Samenow. "Intra-urban societal vulnerability to extreme heat: the role of heat exposure and the built environment, socioeconomics, and neighborhood stability." *Health & Place* 17, no. 2 (2011): 498-507.
- 95 Bouchama, Abderrezak, and James P. Knochel. "Heat stroke." *New England Journal of Medicine* 346, no. 25 (2002): 1978-1988.
- 96 Kjellstrom, Tord, Ingvar Holmer, and Bruno Lemke. "Workplace heat stress, health and productivity—an increasing challenge for low and middle-income countries during climate change." *Global Health Action* 2, no. 1 (2009): 2047.
- 97 Basu, R. and Ostro, B.D., 2008. A multicounty analysis identifying the populations vulnerable to mortality associated with high ambient temperature in California. *American journal of epidemiology*, 168(6), pp.632-637.

- 98 Sokolnicki, Lynn A., Nicholas A. Strom, Shelly K. Roberts, Shirley A. Kingsley-Berg, Ananda Basu, and Nisha Charkoudian. "Skin blood flow and nitric oxide during body heating in type 2 diabetes mellitus." *Journal of Applied Physiology* 106, no. 2 (2009): 566-570.
- 99 Kovats, R. Sari, and Shakoor Hajat. "Heat stress and public health: a critical review." *Annu. Rev. Public Health* 29 (2008): 41-55.
- 100 Fouillet, Anne, Grégoire Rey, Françoise Laurent, Gérard Pavillon, Stéphanie Bellec, Chantal Guihenneuc-Jouyaux, Jacqueline Clavel, Eric Jouglu, and Denis Hémon. "Excess mortality related to the August 2003 heat wave in France." *International archives of occupational and environmental health* 80, no. 1 (2006): 16-24.
- 101 World Weather Attribution. "Euro-Mediterranean Heat – Summer 2017". [www.climatecentral.org/analyses/euro-mediterranean-heat-summer-2017](http://www.climatecentral.org/analyses/euro-mediterranean-heat-summer-2017), September 2017
- 102 Russo, Simone, Jana Sillmann, and Andreas Sterl. "Humid heat waves at different warming levels." *Scientific Reports* 7 (2017).
- 103 Watts, Nick, Markus Amann, Sonja Ayeb-Karlsson, Kristine Belesova, Timothy Bouley, Maxwell Boykoff, Peter Byass et al. "The Lancet Countdown on health and climate change: from 25 years of inaction to a global transformation for public health." *The Lancet* (2017).
- 104 Gasparrini, Antonio, Yuming Guo, Francesco Sera, Ana Maria Vicedo-Cabrera, Veronika Huber, Shilu Tong, Micheline de Sousa Zanotti Stagliorio Coelho et al. "Projections of temperature-related excess mortality under climate change scenarios." *The Lancet Planetary Health* (2017).
- 105 Kovats, R. Sari, and Shakoor Hajat. "Heat stress and public health: a critical review." *Annu. Rev. Public Health* 29 (2008): 41-55.
- 106 Takahashi, Shunichi, Takashi Nakamura, Manabu Sakamizu, Robert van Woesik, and Hideo Yamasaki. "Repair machinery of symbiotic photosynthesis as the primary target of heat stress for reef-building corals." *Plant and Cell Physiology* 45, no. 2 (2004): 251-255.
- 107 Steffen W, Sanderson A, Tyson PD et al. (2004) *Global Change and the Earth System: A Planet Under Pressure*. The IGBP Book Series. Berlin, Heidelberg, New York: Springer-Verlag
- 108 Kovats, R. Sari, and Shakoor Hajat. "Heat stress and public health: a critical review." *Annu. Rev. Public Health* 29 (2008): 41-55.
- 109 World Weather Attribution. "Euro-Mediterranean Heat – Summer 2017". [www.climatecentral.org/analyses/euro-mediterranean-heat-summer-2017](http://www.climatecentral.org/analyses/euro-mediterranean-heat-summer-2017), September 2017
- 110 Honda, Yasushi, Masaji Ono, Akihiko Sasaki, and Iwao Uchiyama. "Shift of the short-term temperature mortality relationship by a climate factor-some evidence necessary to take account of in estimating the health effect of global warming." *Journal of Risk Research* 1, no. 3 (1998): 209-220.
- 111 Kovats, R. Sari, and Shakoor Hajat. Ibid
- 112 Fouillet et al, Ibid
- 113 World Weather Attribution. Ibid
- 114 Anderson, G. Brooke, and Michelle L. Bell. "Lights out: impact of the August 2003 power outage on mortality in New York, NY." *Epidemiology (Cambridge, Mass.)* 23, no. 2 (2012): 189.
- 115 Zhang, Ying, Peng Bi, and Janet E. Hiller. "Projected burden of disease for Salmonella infection due to increased temperature in Australian temperate and subtropical regions." *Environment international* 44 (2012): 26-30.
- 116 World Bank Group. "Geographic Hotspots. For World Bank Action on Climate Change and Health". Investing in Climate Change and Health Series. World Bank Group, 2017.
- 117 Russo, Simone, Jana Sillmann, and Andreas Sterl. "Humid heat waves at different warming levels." *Scientific Reports* 7 (2017).
- 118 Park, Chang-Eui, Su-Jong Jeong, Manoj Joshi, Timothy J. Osborn, Chang-Hoi Ho, Shilong Piao, Deliang Chen et al. "Keeping global warming within 1.5° C constrains emergence of aridification." *Nature Climate Change* (2018): 1.
- 119 IGBP, IOC. "SCOR (2013) Ocean Acidification Summary for Policymakers—Third Symposium on the Ocean in a High-CO<sub>2</sub> World." International Geosphere-Biosphere Programme. Stockholm, Sweden.
- 120 Rhein, Monika., Rintoul, Stephen R., 'Observations: Ocean'. IPCC WG1 AR5 Chapter 3. See: [https://www.ipcc.ch/pdf/assessmentreport/ar5/wg1/WG1AR5\\_Chapter03\\_FINAL.pdf](https://www.ipcc.ch/pdf/assessmentreport/ar5/wg1/WG1AR5_Chapter03_FINAL.pdf)
- 121 Neumann, Barbara, Athanasios T. Vafeidis, Juliane Zimmermann, and Robert J. Nicholls. "Future coastal population growth and exposure to sea-level rise and coastal flooding—a global assessment." *PloS one* 10, no. 3 (2015): e0118571.
- 122 Myers, Samuel S., Antonella Zanobetti, Itai Kloog, Peter Huybers, Andrew DB Leakey, Arnold J. Bloom, Eli Carlisle et al. "Increasing CO<sub>2</sub> threatens human nutrition." *Nature* 510,

- no. 7503 (2014): 139-142
- 123 Nelson, Gerald C., Mark W. Rosegrant, Jawoo Koo, Richard Robertson, Timothy Sulser, Tingju Zhu, Claudia Ringler et al. *Climate change: Impact on agriculture and costs of adaptation*. Vol. 21. Intl Food Policy Res Inst, 2009.
  - 124 Springmann, Marco, Daniel Mason-D'Croz, Sherman Robinson, Tara Garnett, H. Charles J. Godfray, Douglas Gollin, Mike Rayner, Paola Ballon, and Peter Scarborough. "Global and regional health effects of future food production under climate change: a modelling study." *The Lancet* 387, no. 10031 (2016): 1937-1946.
  - 125 Fanzo, Jessica, Rebecca McLaren, Claire Davis, and Jowel Choufani. "Climate change and variability: What are the risks for nutrition, diets, and food systems?" (2017).
  - 126 Scheelbeek, P. F., A. Haines, Sontosh K. Mojumder, Marta AG Blangiardo, and Paul Elliott. "Drinking Water Salinity and Raised Blood Pressure: Evidence from a Cohort Study in Coastal Bangladesh." *Environmental health perspectives* 125, no. 5 (2017): 057007.
  - 127 World Health Organization. "Connecting Global Priorities: Biodiversity and Human Health." World Health Organization and Secretariat of the Convention on Biological Diversity, 2015.
  - 128 Gonthier, David J., Katherine K. Ennis, Serge Farinas, Hsun-Yi Hsieh, Aaron L. Iverson, Péter Batáry, Jörgen Rudolphi, Teja Tscharnkte, Bradley J. Cardinale, and Ivette Perfecto. "Biodiversity conservation in agriculture requires a multi-scale approach." *Proceedings of the Royal Society of London B: Biological Sciences* 281, no. 1791 (2014): 20141358.
  - 129 Shochat, Eyal, Susannah B. Lerman, John M. Anderies, Paige S. Warren, Stanley H. Faeth, and Charles H. Nilon. "Invasion, competition, and biodiversity loss in urban ecosystems." *BioScience* 60, no. 3 (2010): 199-208.
  - 130 Tsiafouli, Maria A., Elisa Thébault, Stefanos P. Sgardelis, Peter C. Ruiter, Wim H. Putten, Klaus Birkhofer, Lia Hemerik et al. "Intensive agriculture reduces soil biodiversity across Europe." *Global change biology* 21, no. 2 (2015): 973-985.
  - 131 Rodríguez, Rolando, Pamela Encina, Miguel Espinosa, and Norio Tanaka. "Field study on planted forest structures and their role in protecting communities against tsunamis: experiences along the coast of the Biobío Region, Chile." *Landscape and ecological engineering* 12, no. 1 (2016): 1-12.
  - 132 Escudero-Castillo, Mireille, Angélica Felix-Delgado, Rodolfo Silva, Ismael Mariño-Tapia, and Edgar Mendoza. "Beach erosion and loss of protection environmental services in Cancun, Mexico." *Ocean & Coastal Management* (2017).
  - 133 McLellan, Richard, Leena Iyengar, Barney Jeffries, and Nastasja Oerlemans, eds. *Living Planet Report 2014: species and spaces, people and places*. World Wide Fund for Nature, 2014.
  - 134 EU Directive, "Directive 2010/75/EU of the European Parliament and of the Council of 24 November 2010 on industrial emissions (Integrated Pollution Prevention and Control)." *Official Journal of the European Union* L 334 (2010): 17-119.
  - 135 Ellis, Erle C., Erica C. Antill, and Holger Kreft. "All is not loss: plant biodiversity in the Anthropocene." *PloS one* 7, no. 1 (2012): e30535.
  - 136 The World Bank Data. "Agricultural land (% of land area)". See <https://data.worldbank.org/indicator/AG.LND.AGRI.ZS>, last accessed 05 December 2017
  - 137 Godfray, H. Charles J., John R. Beddington, Ian R. Crute, Lawrence Haddad, David Lawrence, James F. Muir, Jules Pretty, Sherman Robinson, Sandy M. Thomas, and Camilla Toulmin. "Food security: the challenge of feeding 9 billion people." *science* 327, no. 5967 (2010): 812-818.
  - 138 Millennium Ecosystem Assessment. "Millennium ecosystem assessment." *Ecosystems and human wellbeing: a framework for assessment* Washington, DC: Island Press (2005).
  - 139 Bakarr, Muhammad. "Crop Biodiversity." (2017).
  - 140 FAO, 1997. *State of the world's plant genetic resources for food and agriculture*. FAO, Rome
  - 141 IUCN, "Facts and Figures on biodiversity", 1 Jan, 2012 <https://www.iucn.org/content/facts-and-figures-biodiversity>
  - 142 Galluzzi, G., C. Van Duijvendijk, L. Collette, N. Azzu, and T. Hodgkin. "Biodiversity for Food and Agriculture. Contributing to food security and sustainability in a changing world." PAR platform, FAO, Rome (2011).
  - 143 Barnett, Adrian. "The Nature of crops: why do we eat so few of the edible plants?" *New Scientist Review*, 15 July 2015
  - 144 Warren, John. *The Nature of Crops: How We Came to Eat the Plants We Do*. CABI, 2015.
  - 145 Millennium Ecosystem Assessment, Ibid
  - 146 Millennium Ecosystem Assessment, Ibid
  - 147 Ristaino, Jean Beagle. "Tracking historic migrations of the Irish potato famine pathogen, *Phytophthora infestans*." *Microbes and infection* 4, no. 13 (2002): 1369-1377.
  - 148 Ordóñez, Nadia, Michael F. Seidl, Cees Waalwijk, André

- Drenth, Andrzej Kilian, Bart PHJ Thomma, Randy C. Ploetz, and Gert HJ Kema. "Worse comes to worst: bananas and Panama disease—when plant and pathogen clones meet." *PLoS pathogens* 11, no. 11 (2015): e1005197.
- 149 Burlingame, B., Charrondiere, R., & Mouille, B. (2009). Food composition is fundamental to the cross-cutting initiative on biodiversity for food and nutrition. *Journal of Food Composition and Analysis*, 22(5), 361–365.
  - 150 Kennedy, Gina, and Barbara Burlingame. "Analysis of food composition data on rice from a plant genetic resources perspective." *Food Chemistry* 80, no. 4 (2003): 589–596.
  - 151 Munzuroglu, Omer, Fikret Karatas, and Hikmet Geckil. "The vitamin and selenium contents of apricot fruit of different varieties cultivated in different geographical regions." *Food Chemistry* 83, no. 2 (2003): 205–212.
  - 152 Hatloy, A., Torheim, L., & Oshaug, A. (1998). Food variety Ð a good indicator of nutritional adequacy of the diet? A case study from an urban area in Mali, West Africa. *Eur J Clin Nutr*, 52, 891–8
  - 153 Johns, Timothy. "Dietary diversity, global change and human health." In *Proceedings of the Symposium Managing Biodiversity in Agricultural Ecosystems*, Nov, pp. 8–10. 2001.
  - 154 FAO, 1997. State of the world's plant genetic resources for food and agriculture. FAO, Rome
  - 155 Krishna, Sanjeev, Leyla Bustamante, Richard K. Haynes, and Henry M. Staines. "Artemisinins: their growing importance in medicine." *Trends in pharmacological sciences* 29, no. 10 (2008): 520–527.
  - 156 Barton, Debra L., Gamini S. Soori, Brent A. Bauer, Jeff A. Sloan, Patricia A. Johnson, Cesar Figueras, Steven Duane et al. "Pilot study of *Panax quinquefolius* (American ginseng) to improve cancer-related fatigue: a randomized, double-blind, dose-finding evaluation: NCCTG trial N03CA." *Supportive Care in Cancer* 18, no. 2 (2010): 179.
  - 157 Giri, Archana, and M. Lakshmi Narasu. "Production of podophyllotoxin from *Podophyllum hexandrum*: a potential natural product for clinically useful anticancer drugs." *Cytotechnology* 34, no. 1–2 (2000): 17–26.
  - 158 Ratnadass, Alain, Paula Fernandes, Jacques Avelino, and Robert Habib. "Plant species diversity for sustainable management of crop pests and diseases in agroecosystems: a review." *Agronomy for sustainable development* 32, no. 1 (2012): 273–303.
  - 159 Dobson A., Campbell, M.S. and Bell, J., "Chapter 4: Fatal Synergisms: Interactions Between Infectious Diseases, Human Population Growth and Loss of Biodiversity" in Grifo, F., & Rosenthal, J. (Eds.). (1997). *Biodiversity and human health*. Island Press.
  - 160 Keesing, Felicia, Lisa K. Belden, Peter Daszak, Andrew Dobson, C. Drew Harvell, Robert D. Holt, Peter Hudson et al. "Impacts of biodiversity on the emergence and transmission of infectious diseases." *Nature* 468, no. 7324 (2010): 647–652.
  - 161 Rulli, Maria Cristina, Monia Santini, David TS Hayman, and Paolo D'Odorico. "The nexus between forest fragmentation in Africa and Ebola virus disease outbreaks." *Scientific Reports* 7 (2017): 41613.
  - 162 EU Directive, "Directive 2010/75/EU of the European Parliament and of the Council of 24 November 2010 on industrial emissions (Integrated Pollution Prevention and Control)." *Official Journal of the European Union L 334* (2010): 17–119
  - 163 Angold, P. G., Jon P. Sadler, Mark O. Hill, Andrew Pullin, Steven Rushton, K. Austin, Emma Small et al. "Biodiversity in urban habitat patches." *Science of the Total environment* 360, no. 1 (2006): 196–204.
  - 164 Strachan, David P. "Hay fever, hygiene, and household size." *BMJ: British Medical Journal* 299, no. 6710 (1989): 1259.
  - 165 Rook, G. A. (2013). Regulation of the immune system by biodiversity from the natural environment: an ecosystem service essential to health. *Proceedings of the National Academy of Sciences*, 110(46), 18360–18367
  - 166 Rook, Graham, Fredrik Bäckhed, Bruce R. Levin, Margaret J. McFall-Ngai, and Angela R. McLean. "Evolution, human-microbe interactions, and life history plasticity." *The Lancet* 390, no. 10093 (2017): 521–530.
  - 167 Rook et al, *Ibid*
  - 168 Ownby, Dennis R., and Christine C. Johnson. "Does exposure to dogs and cats in the first year of life influence the development of allergic sensitization?" *Current opinion in allergy and clinical immunology* 3, no. 6 (2003): 517–522.
  - 169 White, Mathew, Amanda Smith, Kelly Humphryes, Sabine Pahl, Deborah Snelling, and Michael Depledge. "Blue space: The importance of water for preference, affect, and restorativeness ratings of natural and built scenes." *Journal of Environmental Psychology* 30, no. 4 (2010): 482–493.
  - 170 Völker, Sebastian, and Thomas Kistemann. "The impact of blue space on human health and well-being—Salutogenetic health effects of inland surface waters: A review." *International journal of hygiene and environmental health* 214, no. 6 (2011): 449–460.

- 171 World Health Organization. "Healthy environments for children: Initiating an alliance for action." (2002).
- 172 World Health Organization. "Connecting Global Priorities: Biodiversity and Human Health." World Health Organization and Secretariat of the Convention on Biological Diversity, 2015.
- 173 Pretty, Jules, Bill Adams, Fikret Berkes, Simone Ferreira de Athayde, Nigel Dudley, Eugene Hunn, Luisa Maffi et al. "How do biodiversity and culture intersect." In Plenary paper for Conference "Sustaining cultural and biological diversity in a rapidly changing world. 2008.
- 174 Dadvand, Payam, Xavier Bartoll, Xavier Basagaña, Albert Dalmau-Bueno, David Martinez, Albert Ambros, Marta Cirach et al. "Green spaces and general health: roles of mental health status, social support, and physical activity." *Environment international* 91 (2016): 161-167.
- 175 World Health Organization. "Connecting Global Priorities: Biodiversity and Human Health." World Health Organization and Secretariat of the Convention on Biological Diversity, 2015.
- 176 Keniger, Lucy E., Kevin J. Gaston, Katherine N. Irvine, and Richard A. Fuller. "What are the benefits of interacting with nature?" *International journal of environmental research and public health* 10, no. 3 (2013): 913-935.
- 177 Louv, Richard. *Last child in the woods: Saving our children from nature-deficit disorder*. Algonquin Books, 2008.
- 178 Driessnack, Martha. "Children and Nature—Deficit Disorder." *Journal for Specialists in Pediatric Nursing* 14, no. 1 (2009): 73-75.
- 179 Frumkin, Howard, Gregory N. Bratman, Sara Jo Breslow, Bobby Cochran, Peter H. Kahn Jr, Joshua J. Lawler, Phillip S. Levin et al. "Nature contact and human health: A research agenda." *Environmental Health Perspectives* 125, no. 7 (2017): 075001-1.
- 180 Millennium Ecosystem Assessment. "Millennium ecosystem assessment." *Ecosystems and human wellbeing: a framework for assessment* Washington, DC: Island Press (2005).
- 181 Landrigan, Philip J., Richard Fuller, Nereus JR Acosta, Olusoji Adeyi, Robert Arnold, Abdoulaye Bibi Baldé, Roberto Bertollini et al. "The Lancet Commission on pollution and health." *The Lancet* (2017).
- 182 Landrigan et al, *Ibid*
- 183 Zhang, Qiang, Xujia Jiang, Dan Tong, Steven J. Davis, Hongyan Zhao, Guannan Geng, Tong Feng et al. "Transboundary health impacts of transported global air pollution and international trade." *Nature* 543, no. 7647 (2017): 705-709.
- 184 Prüss-Üstün, Annette, and M. Neira. "Preventing disease through healthy environments: a global assessment of the burden of disease from environmental risks". World Health Organization, 2016.
- 185 Bølling, A. K., Pagels, J., Yttri, K. E., Barregard, L., Sallsten, G., Schwarze, P. E., & Boman, C. (2009). Health effects of residential wood smoke particles: the importance of combustion conditions and physicochemical particle properties. *Particle and fibre toxicology*, 6(1), 29.
- 186 Boy, Erick, Nigel Bruce, and Hernán Delgado. "Birth weight and exposure to kitchen wood smoke during pregnancy in rural Guatemala." *Environmental health perspectives* 110, no. 1 (2002): 109.
- 187 Siddiqui, Amna R., Ellen B. Gold, Xiaowei Yang, Kiyoun Lee, Kenneth H. Brown, and Zulfiqar A. Bhutta. "Prenatal exposure to wood fuel smoke and low birth weight." *Environmental health perspectives* 116, no. 4 (2008): 543.
- 188 Prüss-Üstün, Annette, and M. Neira. "Preventing disease through healthy environments: a global assessment of the burden of disease from environmental risks". World Health Organization, 2016.
- 189 Fleischer, Nancy L., Mario Meriardi, Aaron van Donkelaar, Felipe Vadillo-Ortega, Randall V. Martin, Ana Pilar Betran, and João Paulo Souza. "Outdoor air pollution, preterm birth, and low birth weight: analysis of the world health organization global survey on maternal and perinatal health." *Environmental health perspectives* 122, no. 4 (2014): 425.
- 190 Eze, Ikenna C., Lars G. Hemkens, Heiner C. Bucher, Barbara Hoffmann, Christian Schindler, Nino Künzli, Tamara Schikowski, and Nicole M. Probst-Hensch. "Association between ambient air pollution and diabetes mellitus in Europe and North America: systematic review and meta-analysis." *Environmental health perspectives* 123, no. 5 (2015): 381.
- 191 Lelieveld, Jos, J. S. Evans, M. Fnais, Despina Giannadaki, and A. Pozzer. "The contribution of outdoor air pollution sources to premature mortality on a global scale." *Nature* 525, no. 7569 (2015): 367-371.
- 192 Prüss-Üstün, Annette, and M. Neira. "Preventing disease through healthy environments: a global assessment of the burden of disease from environmental risks". World Health Organization, 2016
- 193 Lin, Ro-Ting, Ken Takahashi, Antti Karjalainen, Tsutomu Hoshuyama, Donald Wilson, Takashi Kameda, Chang-Chuan Chan et al. "Ecological association between asbestos-related diseases and historical asbestos consumption: an international

- analysis." *The Lancet* 369, no. 9564 (2007): 844-849.
- 194 Diffey, B. L. (1992). Ozone depletion and skin cancer. *BMJ: British Medical Journal*, 304(6835), 1176.
  - 195 Chatham-Stephens, Kevin, Jack Caravanos, Bret Ericson, Jennifer Sunga-Amparo, Budi Susilorini, Promila Sharma, Philip J. Landrigan, and Richard Fuller. "Burden of disease from toxic waste sites in India, Indonesia, and the Philippines in 2010." *Environmental health perspectives* 121, no. 7 (2013): 791.
  - 196 Wilson, Clevo, and Clem Tisdell. "Why farmers continue to use pesticides despite environmental, health and sustainability costs." *Ecological economics* 39, no. 3 (2001): 449-462.
  - 197 Whitmee, Sarah, Andy Haines, Chris Beyrer, Frederick Boltz, Anthony G. Capon, Braulio Ferreira de Souza Dias, Alex Ezeh et al. "Safeguarding human health in the Anthropocene epoch: report of The Rockefeller Foundation-Lancet Commission on planetary health." *The Lancet* 386, no. 10007 (2015): 1973-2028.
  - 198 Telmer, Kevin H., and Marcello M. Veiga. "World emissions of mercury from artisanal and small scale gold mining." In *Mercury fate and transport in the global atmosphere*, pp. 131-172. Springer US, 2009.
  - 199 Nevin, R. (2007). Understanding international crime trends: the legacy of preschool lead exposure. *Environmental research*, 104(3), 315-336.
  - 200 Pure Earth/Green Cross. "2016 The World's Worst Pollution Problems: The Toxins Beneath Our Feet." Green Cross Switzerland (2016).
  - 201 Grosse, Scott D., Thomas D. Matte, Joel Schwartz, and Richard J. Jackson. "Economic gains resulting from the reduction in children's exposure to lead in the United States." *Environmental health perspectives* 110, no. 6 (2002): 563.
  - 202 Grandjean, Philippe, and Philip J. Landrigan. "Developmental neurotoxicity of industrial chemicals." *The Lancet* 368, no. 9553 (2006): 2167-2178.
  - 203 Grandjean, Philippe, and Philip J. Landrigan. "Neurobehavioural effects of developmental toxicity." *The Lancet Neurology* 13, no. 3 (2014): 330-338.
  - 204 Gore, A. C., V. A. Chappell, S. E. Fenton, J. A. Flaws, A. Nadal, G. S. Prins, J. Toppari, and R. T. Zoeller. "Executive summary to EDC-2: the endocrine society's second scientific statement on endocrine-disrupting chemicals." *Endocrine reviews* 36, no. 6 (2015): 593-602.
  - 205 Larsson, DG Joakim. "Pollution from drug manufacturing: review and perspectives." *Phil. Trans. R. Soc. B* 369, no. 1656 (2014): 20130571.
  - 206 Nelson, Gerald C., Mark W. Rosegrant, Jawoo Koo, Richard Robertson, Timothy Sulser, Tingju Zhu, Claudia Ringler et al. *Climate change: Impact on agriculture and costs of adaptation*. Vol. 21. Intl Food Policy Res Inst, 2009.
  - 207 Tyree, Chris., and Morrison, Dan. "Invisibles: the plastics inside us". Orb Media [https://orbmedia.org/stories/Invisibles\\_plastics](https://orbmedia.org/stories/Invisibles_plastics) Accessed 31 October 2017
  - 208 Clapp, Brian William. *An environmental history of Britain since the Industrial Revolution*. Routledge, 2014.
  - 209 Schwarzenbach, René P., Thomas Egli, Thomas B. Hofstetter, Urs von Gunten, and Bernhard Wehrli. "Global water pollution and human health." *Annual Review of Environment and Resources* 35 (2010): 109-136.
  - 210 Wilkinson, Paul, Kirk R. Smith, Sean Beevers, Cathryn Tonne, and Tadj Oreszczyn. "Energy, energy efficiency, and the built environment." *The Lancet* 370, no. 9593 (2007): 1175-1187.
  - 211 Prüss-Üstün, Annette, and M. Neira. "Preventing disease through healthy environments: a global assessment of the burden of disease from environmental risks". World Health Organization, 2016.
  - 212 Margai, Florence M., and Fatoumata B. Barry. "Global geographies of environmental injustice and health: a case study of illegal hazardous waste dumping in Cote d'Ivoire." In *Geospatial Analysis of Environmental Health*, pp. 257-281. Springer Netherlands, 2011.
  - 213 Margai et al, Ibid
  - 214 Eskeland, Gunnar S., and Ann E. Harrison. "Moving to greener pastures? Multinationals and the pollution haven hypothesis." *Journal of development economics* 70, no. 1 (2003): 1-23.
  - 215 Watkins, Beverly Xaviera, Peggy Morrow Shepard, and Cecil D. Corbin-Mark. "Completing the circle: a model for effective community review of environmental health research." *American journal of public health* 99, no. S3 (2009): S567-S577.
  - 216 Basu, R. and Ostro, B.D., 2008. A multicounty analysis identifying the populations vulnerable to mortality associated with high ambient temperature in California. *American journal of epidemiology*, 168(6), pp.632-637.
  - 217 Basu et al, Ibid.
  - 218 Watts, Nick, W. Neil Adger, Paolo Agnolucci, Jason Blackstock, Peter Byass, Wenjia Cai, Sarah Chaytor et al. "Health and climate change: policy responses to protect public health." *The Lancet* 386, no. 10006 (2015): 1861-1914.



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## About the Oxford Martin School

The Oxford Martin School at the University of Oxford is a world-leading centre of pioneering research that addresses global challenges. It invests in research that cuts across disciplines to tackle a wide range of issues such as climate change, disease and inequality. The School supports novel, high risk and multidisciplinary projects that may not fit within conventional funding channels, because breaking boundaries can produce results that could dramatically improve the wellbeing of this and future generations. Underpinning all our research is the need to translate academic excellence into impact – from innovations in science, medicine and technology, through to providing expert advice and policy recommendations.

**The Rockefeller Foundation Economic Council on Planetary Health**

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