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Health Impacts of Climate Change and the Health Benefits of Climate Change Action: A Review of the Literature

A Department of Health Research Paper, 2019

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Executive Summary

The purpose of this literature review is to summarise evidence on climate change impacts on human health and the health benefits of climate action. In Ireland, climate changes observed are in line with global trends with such changes projected to continue, and indeed increase, over the coming years. Common messages from conceptual frameworks for understanding how climate change can impact on health are:

1. Climate change can influence health through altering exposure to stressors such as extreme weather events; vector-, food- and waterborne infectious diseases; changes in the quality and safety of air, food, and water; and stresses to mental health and well-being.

2. Exposures that result from climate change can be categorised as exposures with direct health impacts (e.g. storm, drought, flood, heat wave, temperature change, wildfires) or exposures with indirect health impacts (e.g. water quality, air quality, land use change, ecological change).

3. The extent to which exposures which result from climate change impacts on health will be influenced by mediating factors. These include:

    - individual or social factors such as demographics, socio-economics, health status, access to care, conflict.
    - environmental factors for example geography, baseline weather, air and water quality, vegetation.
    - institutional capacity such as primary health care, warning systems.

4. The potential climate change impacts on health are wide ranging such as deaths, injuries, respiratory disease, heat stroke, poisoning, water-borne diseases, infectious diseases, under nutrition, mental illness.

International evidence on the health impacts of climate change are summarised below.

1. Direct Impacts
Heat and cold*:* increase in heat-related deaths, decrease in cold-related deaths. **Floods and storms***:* deaths (e.g. drowning), injuries, hypothermia, and infectious diseases, and mental health (psychological distress, anxiety, and depression). **Ultraviolet radiation**: increase in melanoma and non-melanoma skin cancers and damage to eyes (e.g. ocular cataracts resulting in vision loss).
2. Ecosystem Mediated Impacts
Vector-borne and other infectious diseases: increase in infections transmitted via mosquitos and

ticks (e.g. Lyme disease, malaria, dengue, tick-borne encephalitis). **Food and water-borne infections**: increase of infection via water-borne organisms and pathogens (e.g. vibrio-related pathogens such as cholera), parasites and enteric viruses within food and rotavirus infections. **Air quality**: increase in premature deaths associated with high levels of ozone exposure, increase in deaths attributed to toxic air pollution resulting from wildfires, increase in infections and reactions associated with aeroallergens.
3. Institutional Mediated Impacts (i.e. via economic and social disrupt)
Nutrition: increase in conditions associated with chronic undernutrition (e.g. stunted height growth) and acute under nutrition (e.g. low weight and underweight). **Occupational health**: increase in health hazards for outdoor labourers depending on climate and occupation (e.g. dehydration, heat-stress, vector-borne diseases) **Mental health**: increase in stress and trauma-related mental illness around climate disasters (e.g. post-traumatic stress, generalised anxiety disorder, depression and complex psychopathology), increase in psychological stress around slower climate events such as drought (e.g. may result in higher frequency of suicide). **Violence and conflict**: increase in conflict-related deaths and injuries due to population pressures from weather-related disasters and gradual events (e.g. scarcity around access to food, water or shelter.)

Most of the evidence for Ireland relates to studies identifying future threats to health rather than establishing past impacts. “The key climate change related exposures of importance to human health are likely to be increases in heat wave-related health impacts, decreases in cold-related health impacts, increases in flood-related health impacts, changes in patterns of food-borne disease, an increase in the burden of water-borne disease and an increase in the frequency of respiratory diseases due to changes in pollen and pollutant distributions (temporal and spatial).” (Desmond, O’Brien & McGovern, 2017).

Health gains can occur from key climate change actions (“co-benefits”) such as:

- Increasing consumption of diets with low greenhouse gas emissions and improving agriculture and good waste practices.
- Reducing co-pollutants from household solid fuel combustion, better lighting and application of passive design principles.
- Reducing greenhouse gases and associated co-pollutants from industrial sources.
- Increasing energy efficiency, reducing demand for fossil fuels and increasing demand renewable energy.
- Increasing green areas in urban spaces.
- Increasing active travel, modifications to public transport and to the built environment.
- Reducing unmet need for contraception and for family planning services.
- Reducing emissions from deforestation and improving forest management practices.

1. INTRODUCTION

1.1 Purpose and Background

The World Health Organisation has stated that "The severity of the impact of climate change on health is increasingly clear. Climate change is the greatest challenge of the 21st century, threatening all aspects of the society in which we live, and the continuing delay in addressing the scale of the challenge increases the risks to human lives and health." COP24 (WHO, 2018).

Climate and climate change have been summarised by the U.S. Global Change Research Program (USGCRP) as "Climate is the average weather conditions that persist over multiple decades or longer. While the weather can change in minutes or hours, identifying a change in climate has required observations over a time period of decades to centuries or longer. Climate change encompasses both increases and decreases in temperature as well as shifts in precipitation, changing risks of certain types of severe weather events, and changes to other features of the climate system" (Balbus et al., 2016).

The purpose of this report is to summarise evidence on the health impacts of climate change and on the health benefits of climate change mitigation. This report follows on from the recommendation of *The Report of the Joint Committee on Climate Action Climate Change: A Cross-Party Consensus for Action* (March 2019) that "The Department of Health should carry out a review of the health risks associated with climate change and benefits associated with climate action. The results of this review . . . should both be published by June 2019." (p. 36). This literature review is one input to the Health Sectoral Climate Change Adaptation Plan which under the National Adaptation Framework the Department of Health has a statutory obligation to provide by 30th September 2019. The sectoral plan will focus on actions that can be undertaken within the next five years.

Outside the scope of this review is literature on addressing health risks of climate change through adaptation and through building climate-resilient health systems. Efforts to adapt to the health impacts of climate change have be categorized as incremental, transitional, and transformational actions (O'Brien et al., 2012). Incremental adaptation aims to reduce current adaptation deficits. It typically involves improving public health functions such as enhancing disease surveillance, monitoring environmental exposures, improving disaster risk management, and facilitating coordination between health and other sectors to deal with shifts in the incidence and geographic range of diseases (Woodward et al., 2011). Transitional adaptation focuses on how climate change could alter health burdens and the effectiveness of interventions. It increasingly involves the use of vulnerability mapping (to better understand risks related to climate change), early warning systems (to alert public

health authorities and the public about climate-related health risks) and involving other sectors in determining the risks of disease and injury resulting from climate change (Smith et al., 2014). Transformational adaptation requires fundamental changes in systems (Smith et al., 2014). As noted above this literature review is just one input into work to develop a Health Sectoral Climate Change Adaptation Plan.

1.2 Method

1.2.1 Literature Search

The search strategy involved a key word search of peer-reviewed databases. In addition, a key word search of Google and Google Scholar was undertaken. Furthermore, websites of organisations were also searched. These include World Health Organisation (WHO), Organisation for Economic Co-operation and Development (OECD), the European Commission, Centres for Disease Control and Prevention (CDC), European Observatory on Health Systems and Policies and the Environmental Protection Agency (EPA). The key word searches used in the three searches undertaken are shown below.

Table 1-1: Search Terms Used in Each Search

Step 1 Search
A comprehensive search of the international literature was undertaken using Medline, Embase, CINAHL and the Cochrane Library electronic databases. A search of the grey literature was also performed using the Google and Google Scholar websites. The search strategies were constructed using free text searches and also MeSH terms and were designed to identify papers related to the impact of climate change on population health and the delivery of healthcare services. The search terms included: Search #1: climate change OR global warming OR climate variability OR greenhouse effect* OR GHG* Search #2: (MM "Health+") OR (MM "Environmental Health+") OR (MM "Health Planning+") OR (MM "Health Policy+") Search #3: disease* Search #4: mortality or morbidity Search #5: S3 OR S4 Search #6: S1 AND S2 AND S5 Search #7: S1 AND S2 AND S5 Published Date: 19900101-20181231; English Language; Human; English Language; Human The inclusion criteria were as follows: high income country, primary focus was on the impact of climate change on health and wellbeing, papers published between the years 1990 – 2018. The exclusion criteria were as follows: low/middle income country, studies with a primary

focus on the impact of climate change on the occupational health of workers, articles for which access to full article could not be obtained and where the abstract contained insufficient information, studies published in a language other than English.
Step 2 Search
The search of Google and Google Scholar was undertaken using the strings below. The first five pages of search results were searched. "health" AND "climate change" filetype: pdf "health" AND "climate change" Only relevant literature reviews published after 2014 were included.
Step 3 Search
The search of Google and Google Scholar was undertaken using the strings below. The first five pages of search results were searched. "health" AND "climate change" .ie filetype: pdf "health" AND "climate change" AND "Ireland OR Irish" filetype: pdf The same inclusion and exclusion criteria as Phase 1.

1.2.2 Strengths and Limitations

It has been noted elsewhere that there are limitations to the evidence on existing and projected climate change and health impacts (see for example Balbus et al., 2016). A limitation of this literature review is that it is restricted to material published in English and this report does not undertake an assessment of the quality of the studies included. Nevertheless, the majority of the studies cited have undergone a peer review process and details on some of the key sources are provided below.

Table 1-2: Details on Some Key Literature Reviews Used

"IPCC AR5 report". Human Health: Impacts, Adaptation, and Co-Benefits (Smith et al., 2014).
The Intergovernmental Panel on Climate Change (IPCC) is the United Nations body for assessing the science related to climate change. This report examines what is known about the effects of climate change on human health. It "is a scientific assessment based on best available evidence according to the judgment of the authors." The authors note that they searched the English-language literature up to August 2013, focusing primarily on publications since 2007, they drew primarily (but not exclusively) on peer-reviewed journals. Literature was identified using a published protocol and other approaches, including extensive consultation with technical experts in the field. They examined recent substantial reviews to check for any omissions of important work. In selecting citations for the chapter, they "gave priority to publications that were recent (since AR4), comprehensive, added significant new findings to the literature, and included areas or population groups that have not previously been well described or were judged to be particularly policy relevant in other respects".
"USGCRP Scientific Assessment report". USGCRP, 2016: The Impacts of Climate Change on Human Health in the United States: A Scientific Assessment. (Balbus et al., 2016)
The authors' note that "This assessment was developed by a team of more than 100 experts from

8 U.S. Federal agencies (including employees, contractors, and affiliates) to inform public health officials, urban and disaster response planners, decision makers, and other stakeholders within and outside of government who are interested in better understanding the risks climate change presents to human health." The authors note it draws from a large body of scientific peer-reviewed research and other publicly available sources; all sources meet the standards of the Information Quality Act (IQA). The authors noted the report was extensively reviewed by the public and experts.

"COP24 report". COP24 special report: health and climate change. (WHO, 2018)

This report is a contribution from the public health community to support the negotiations of the United Nations Framework Convention on Climate Change (UNFCCC). We refer to it as the COP24 report (WHO, 2018). The report is based on contributions from over 80 health professionals, academic experts, representatives of civil society and international agencies who have worked on climate change and health for over three decades.

"The imperative of climate action to protect human health in Europe." (European Academies Science Advisory Council, 2019).

The report focuses on the detrimental effects of climate change on human health in Europe: describing the evidence for current effects and projected impacts according to different scenarios and reviewing the options for adaptation and for mitigation where that brings co-benefits for health. The authors note their analysis draws on diverse evidence in European populations: they identify increasing risks, particularly in vulnerable groups but we also emphasise the cardinal point that are all affected by climate change.

"A Summary of the State of Knowledge on Climate Change Impacts for Ireland" (Desmond, O'Brien & McGovern, 2017).

This report presents a summary of the state of knowledge on climate change and projected impacts for Ireland. It updates and enhances the information provided in the 2009 Summary of the State of Knowledge on Climate Change Impacts for Ireland report (Desmond et al., 2009). The purpose of this report is to provide an accessible summary of the available information for Ireland. The national information is largely based on Environmental Protection Agency (EPA) funded research and linked research funded by other national bodies, including Met Éireann, the Office of Public Works (OPW) and the Marine Institute, and research carried out by third-level institutes. The authors note the report was supported by the "Climate Ireland" information portal, and it was shaped by the inputs of national experts through a series of stakeholder events held in 2015.

1.3 Climate Change in Ireland

In Ireland, climate changes observed are in line with global trends with such changes projected to continue, and indeed increase, over the coming years (Desmond, O'Brien and McGovern, 2017). Global temperatures are increasing with an average rise in temperature in Ireland of 0.07◦C per decade since the year 1900 (Dwyer, 2014).

Observed physical climate changes for Ireland include (Dwyer, 2014; Desmond, O'Brien and McGovern, 2017; Department of Communications, Climate Action and Environment, 2018):

- An increase in average temperatures (both air and sea surface temperatures) with an increase in the number of warm days and a reduction in the number of frost days observed;
- A change in rainfall patterns with a 5% increase in average annual national rainfall detected between the years 1981-2010 when compared with the time period 1961-1990;
- Increasing concentrations of greenhouse gases;
- An increase in annual sea surface temperature of one degree when compared to the average calculated for the time period 1961-1990;
- A 30% increase in ocean surface acidity since the Industrial Revolution;
- A pattern towards increasing annual mean flows of rivers; and
- A prolongation of the growth season associated with a rise in mean spring air temperature.

Projected climate changes for Ireland include (Dwyer, 2014; Desmond, O'Brien and McGovern, 2017; Department of Communications, Climate Action and Environment, 2018):

- An increase in average annual temperatures of between 0.9-1.7◦C with the greatest increase projected for the East of Ireland;
- An increase of 0.7-2.6◦C in temperature on hot days;
- An increase in temperatures on cold nights of between 1.1-3.1◦C;
- A 50% reduction in the average number of frost days across the country;
- A decrease in mean annual rainfall levels but the number of heavy rainfall events is expected to increase during the autumn and winter seasons;
- An increase in the average length of the growing season;
- A continued rise in mean sea level;
- Decreased energy content of the wind during summer, autumn and spring;
- Changes in the magnitude and frequency of extreme weather events such as storms and flooding; and
- Increased incidences of both high and low flow periods secondary to an intensification of the hydrological cycle.

1.4 How Climate Change Can Impact on Human Health

This literature review identified four conceptual frameworks for understanding how climate change can impact on health. The details are provided in Appendix A but the frameworks share similarities and common messages, namely:

1. Climate change can influence health through **altering exposure to stressors** such as extreme weather events; vector-, food- and waterborne infectious diseases; changes in

the quality and safety of air, food, and water; and stresses to mental health and well-being.

2. Exposures that result from climate change can be categorised as **exposures with direct health impacts** (e.g. storm, drought, flood, heat wave, temperature change, wildfires) or **exposures with indirect health impacts** (e.g. water quality, air quality, land use change, ecological change).

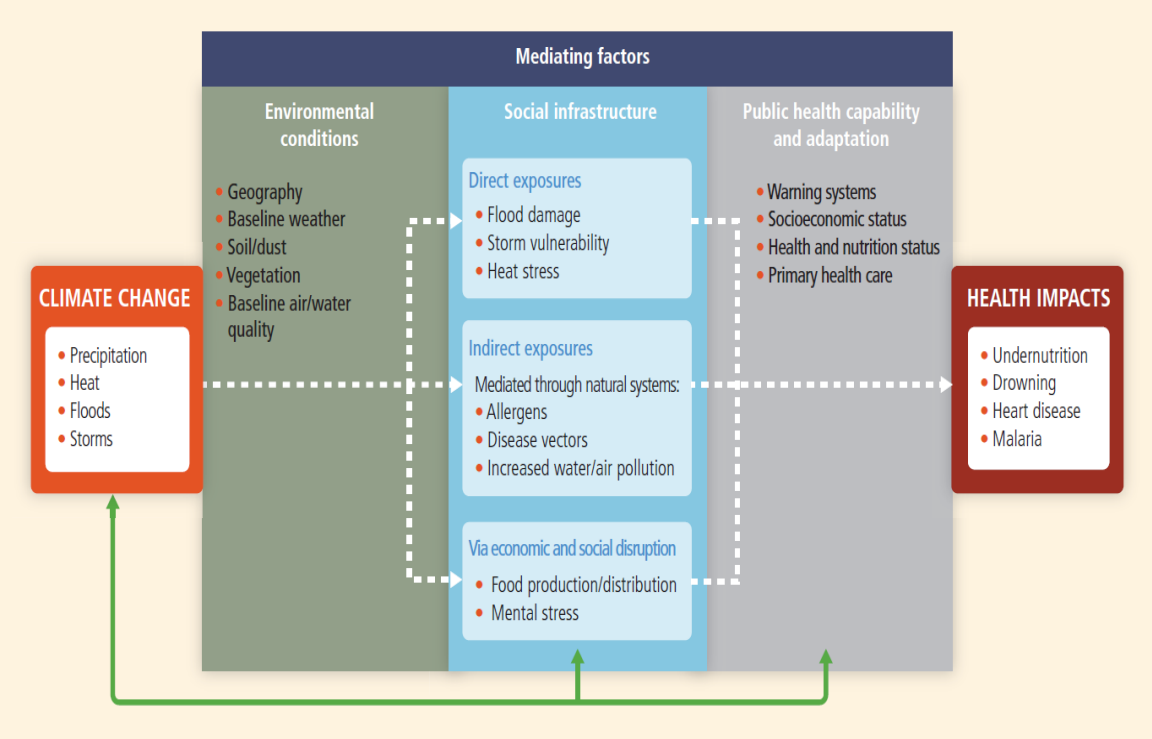
3. The extent to which exposures which result from climate change impacts on health will be influenced by **mediating factors**. These include:

   - *individual or social factors* such as demographics, socio-economics, health status, access to care, conflict.
   - *environmental factors* for example geography, baseline weather, air and water quality, vegetation.
   - *institutional capacity* such as primary health care, warning systems.

4. The potential **climate change impacts on health** are wide ranging such as deaths, injuries, respiratory disease, heat stroke, poisoning, water-borne diseases, infectious diseases, undernutrition, mental illness.

The IPCC Report (Smith et al., 2014) uses the conceptual diagram shown in Figure 1.1. It focuses on three primary exposure pathways by which climate change affects health: directly through weather variables such as heat and storms; indirectly through natural systems such as disease vectors; and pathways heavily mediated through human systems such as undernutrition. This report uses these three exposure pathways when summarising the evidence on health impacts in Chapter Two (international) and Chapter Three (Ireland).

Figure 1-2: Climate Change, Exposure Pathways, Mediating Factors and Health Impacts



Source: IPCC AR5 (Smith et al., 2014)

While the above provides a useful way of categorising the evidence it is important to note there may be more complex pathways. These might include additional health impacts which are "complications" of interactions, e.g. carbon monoxide poisoning risk during flood clean-up, foodborne diseases due to increased ambient temperature allowing accelerated growth of microbiological contaminants, or the health impact of escalation of hazards / risk, e.g. storms that cause power failures which result in failures of systems such as communications, water quality and food quality, which then increase the risks of secondary but serious health impacts.

2. EVIDENCE OF HEALTH IMPACTS INTERNATIONALLY

2.1 Overview

This chapter summarises international evidence on the health impacts of climate change. Table 2.1 summarises the impacts identified. The courses and their predicted impacts on health are summarised and discussed in the subsequent sections. This chapter draws heavily on the IPCC AR5 report (Smith et al., 2014). The findings of which are consistent with more recent literature reviews such as COP24 (WHO, 2018), USGCRP Scientific Assessment (Balbus et al., 2016) and the EASAC policy report 38 (2019).

Table 2-1: Impacts of Climate Change on Global Health

1. Direct Impacts
Heat and cold*:* increase in heat-related deaths, decrease in cold-related deaths. **Floods and storms***:* deaths (e.g. drowning), injuries, hypothermia, and infectious diseases, and mental health (psychological distress, anxiety, and depression). **Ultraviolet radiation**: increase in melanoma and non-melanoma skin cancers, damage to eyes (e.g. ocular cataracts resulting in vision loss).
2. Ecosystem Mediated Impacts
Vector-borne and other infectious diseases: increase in infections transmitted via mosquitos and ticks (e.g. Lyme disease, malaria, dengue, tick-borne encephalitis). **Food and water-borne infections**: increase of infection via water-borne organisms and pathogens (e.g. vibrio-related pathogens such as cholera), parasites and enteric viruses within food and rotavirus infections. **Air quality**: increase in premature deaths associated with high levels of ozone exposure, increase in deaths attributed to toxic air pollution resulting from wildfires, increase in infections and reactions associated with aeroallergens.
3. Institutional Mediated Impacts (i.e. via economic and social disruption)
Nutrition: increase in conditions associated with chronic undernutrition (e.g. stunted height growth) and acute undernutrition (e.g. low weight and underweight). **Occupational health**: increase in health hazards for outdoor labourers depending on climate and occupation (e.g. dehydration, heat-stress, vector-borne diseases) **Mental health**: increase in stress and trauma-related mental illness around climate disasters (e.g. post-traumatic stress, generalised anxiety disorder, depression and complex psychopathology), increase in psychological stress around slower climate events such as drought (e.g. may result in higher frequency of suicide). **Violence and conflict**: increase in conflict-related deaths and injuries due to population pressures from weather-related disasters and gradual events (e.g. scarcity around access to food, water or shelter.)
Source: Smith et al., 2014.

2.2 Direct Impacts

2.2.1 Heat and cold related

The IPCC AR5 report posits that global temperatures have risen over the past few decades, predicting that the risk of heat-related deaths is heightened accordingly. Generally, heat-stress related symptoms such as organ damage, fainting and death become a risk once the human body's temperature exceeds 40.6°C (Smith et al., 2014). However, susceptibility to heat-stress can vary with vulnerability factors such as age, sex, physical activity and pre-existing conditions or chronic illness (Balbus et al., 2016).

Additionally, the report discusses how extreme heat has been associated with increases of events caused by cardiovascular, kidney and respiratory diseases, as seen from hospital admission records. Examples are provided of the rise in heat-related deaths during extreme weather have been seen in heat-wave events, such as the European heat wave of 2003, where more than 15,000 deaths occurred in France as a result (Smith et al., 2014). Approximately 80% of these deaths were people over the age of 75, a group that is particularly vulnerable to heat-related mortality. The report also indicates concerns for outdoor workers, who may be more vulnerable to heat-related mortality due to the level of physical exertion and inadequate safety measures (Smith et al., 2014).

In conjunction with immediate health impacts, record-breaking high temperatures also heighten the risk of wildfires. The IPCC AR5 report predicts that these wildfires have the potential to directly kill many, and indirectly affect the air quality of the surrounding areas causing respiratory diseases or lung failure through toxic air pollution (Smith et al., 2014).

2.2.2 Floods and storms

According to the IPCC AR5 report, flooding due to rises in sea levels and windstorms will have a significant impact on the health of those who reside near coastal areas with few preventative or protective measures (Smith et al., 2014). The direct impacts of flooding on health can be predicted as deaths and injuries associated with drowning, such as hypothermia and other infectious pathogens. Parasites and other water-borne organisms may also see a population increase as water levels increase and temperatures rise (Smith et al., 2014).

Flooding and extreme storms have been found to adversely and significantly affect the mental health of people who experience their effects. The IPCC AR5 report provides evidence that psychological distress, depression and anxiety have been found to be two to five times more common in individuals who reported flooding occurring within their homes compared to individuals who did not experience flooding and weather-related hazards (Smith et al., 2014; Paranjothy et al., 2011). Additionally, these effects could be seen in

individuals who experienced hurricane and flooding-related stress up to two years after the events of Hurricane Katrina.

From the basis of rising sea levels and the increase in flooding-related natural disasters, the IPCC AR5 report (Smith et al., 2014) concludes that it is very likely that significant losses of life and deterioration of health due to flooding and extreme storms will occur this century if no preventative, protective or adaptation measures are put in place.

2.2.3 Ultraviolet radiation

Ultraviolet (UV) radiation may also be a health concern associated with climate change, according to the IPCC AR5 report. UV radiation has been found to affect human health through sun exposure. UV radiation levels are expected to increase in proportion to rising temperatures with an estimated 2% increase per 1°C increase. High levels of exposure to UV radiation is related to the occurrence of melanoma and non-melanoma skin cancers as well as ocular cataracts, which can cause partial loss of vision or premature blindness (Smith et al., 2014). Increased temperatures may also create adverse health effects from UV exposure, as people may be more inclined to spend time outdoors and may use protective measures such as SPF less frequently.

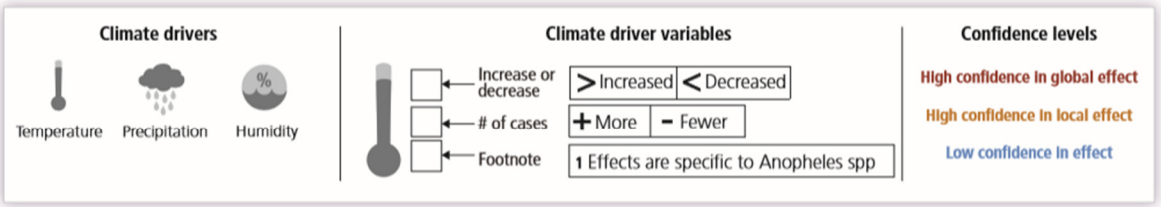
However, the report also provides evidence that increased levels of UV exposure can be beneficial to human health in certain cases. Increased exposure can assist with Vitamin D production and absorption, which can aid in bone growth, calcium absorption and in treating depression. Whether or not increased UV exposure would be beneficial or detrimental to health depends on location, intensity and length of exposure as well as other factors such as diet (Smith et al., 2014).

2.3 Ecosystem Mediated Impacts

2.3.1 Vector-borne diseases (VBDs) and other infectious diseases

Vector-borne diseases (VBDs) are a primary health concern discussed in the IPCC AR5 report. VBDs generally refer to infections that are transmitted by the bite of blood-sucking arthropods (e.g. mosquitoes and ticks). These diseases are heavily associated with climate change and have been widely researched, due to their prevalence and sensitivity to climate-related factors. The figure below from the IPCC AR5 report (Smith et al., 2014) presents what is known about the influence of weather and climate on selected VBDs.

Disease	Area	Cases per year	Climate sensitivity and confidence in climate effect	Key references
Mosquito-borne diseases				
Malaria	Mainly Africa, SE Asia	About 220 million		WHO (2008); Kelly-Hope et al. (2009); Alonso et al. (2011); Omumbo et al. (2011)
Dengue	100 countries, esp. Asia Pacific	About 50 million		Beebe (2009); Pham et al. (2011); Astrom et al. (2012); Earnest et al. (2012); Descloux (2012)
Tick-borne diseases				
Tick-borne encephalitis	Europe, Russian Fed., Mongolia, China	About 10,000		Tokarevich et al. (2011)
Lyme	Temperate areas of Europe, Asia, North America	About 20,000 in USA		Bennet (2006); Ogden et al. (2008)
Other vector-borne diseases				
Hemorrhagic fever with renal syndrome (HFRS)	Global	0.15–0.2 million		Fang et al. (2010)
Plague	Endemic in many locations worldwide	About 40,000		Stenseth et al. (2006); Ari et al. (2010); Xu et al. (2011)



Among the VBDs shown here, only dengue fever was associated with climate variables at both the global and local levels, while malaria and haemorrhagic fever with renal syndrome showed a positive association at the local level.

Source: (Smith et al., 2014).

2.3.2 Food and water-borne diseases

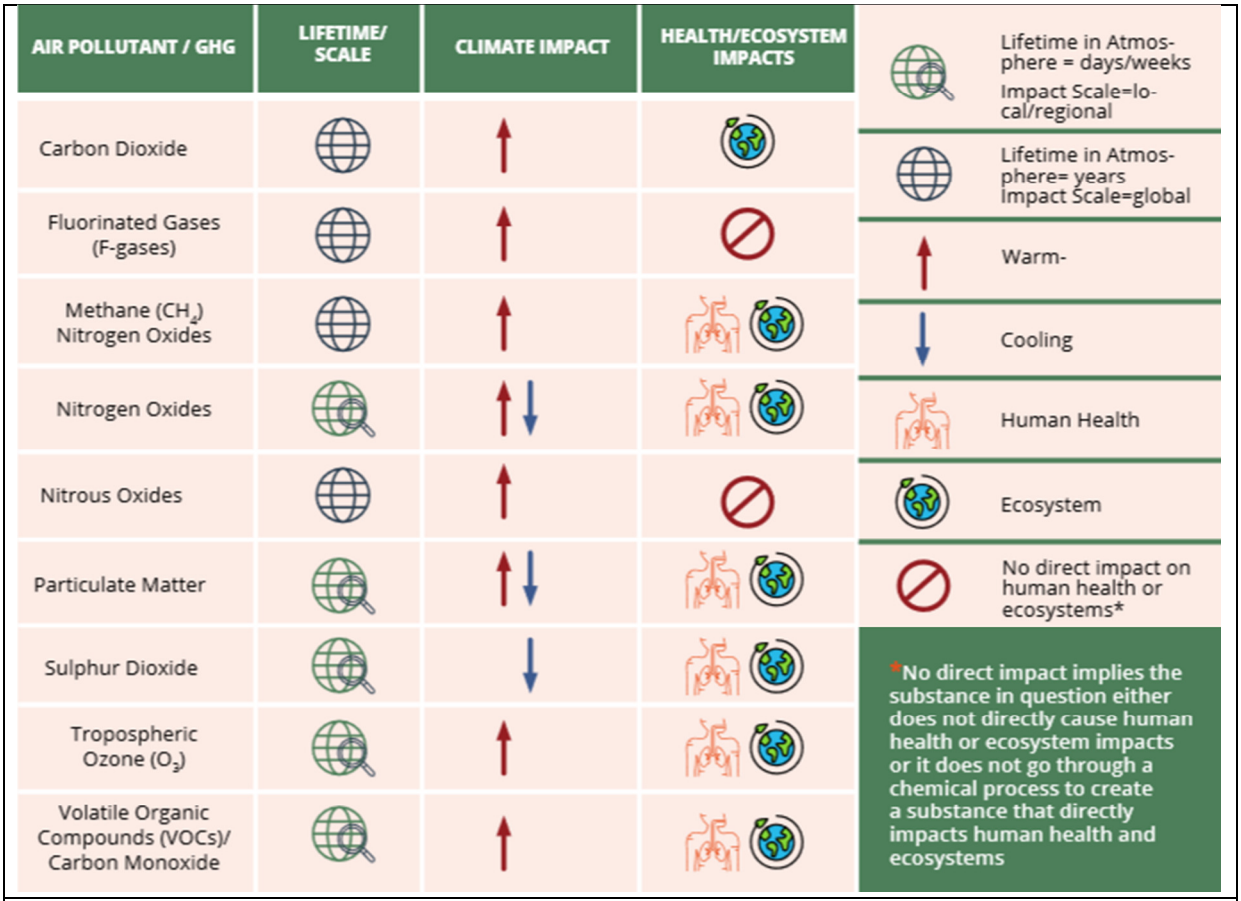
The IPCC AR5 report discusses in detail how climate change may affect food and water-borne diseases. The report predicts that infection rates may increase due to the increased survivability of pathogens in warm and wet climates. Infection can be contracted through ingestion of contaminated water, crops, animals or exposure through ears, eyes and open wounds (Smith et al., 2014). Evidence in this report shows that there is a seasonal association between infection rates, which may be exacerbated by climate change. Water-borne infections could also increase during periods of flooding and increased precipitation, all of which are associated with climate change and increased temperatures (Smith et al., 2014).

2.3.3 Air quality

The vast majority of non-CO_2 climate pollutants are detrimental to human health, through direct or indirect harm. Overall, there is little supporting evidence to confirm that climate change will have a consistent or predictable effect on particle levels over the long-term (Smith et al., 2014).

However, the IPCC AR5 report provides evidence indicating that climate change may enhance chronic exposure to ozone gases. Ozone levels are predicted to rise as temperatures increase especially around urban areas. This is concerning as chronic ozone exposure has been previously linked to risks of cardiopulmonary mortality. Evidence for the dangers of chronic ozone exposure can also be seen in the 2003 European heatwave, where it had been found that up to 50% of deaths during this period could possibly be caused by ozone exposure rather than overheating (Smith et al., 2014).

Furthermore, as noted in the section above, rising temperatures increase the risk of wildfires in areas of drought, causing deaths and injuries as well as toxic air pollution by increasing the levels of toxic particles in the surrounding area. Additionally, aeroallergens such as pollen are expected to increase alongside warmer temperatures, creating a significant impact on those with asthma, allergies and other vulnerable respiratory conditions.



Impacts of different air pollutants and greenhouse gases on climate and health

Source: (WHO, 2018)

2.4 Institutional Mediated Impacts

2.4.1 Nutrition

As high temperatures, extreme weather and high levels of precipitation are predicted from the IPCC AR5 report, it is likely that crop production may see a decrease in quantity or quality of harvests. Farmers and agricultural labourers may experience a decrease in work productivity due to heat-related stress, safety measures to prevent heat morbidity, or extreme weather events. These factors straining agricultural production will likely result in an increase in food prices, causing acute and chronic undernutrition due to further inaccessibility. Acute undernutrition may lead to wasting (low weight for height) and a danger of becoming severely underweight (low weight for age), while chronic undernutrition may lead to stunted height growth (Smith et al., 2014). However, the European Academies EASAC report (2019) shows evidence that countries in Northern Europe may become more suitable for farming certain crops such as cereal due to a warmer climate which may be beneficial to the population's health.

2.4.2 Occupational Health

The report discusses how outdoor labourers such as agriculture or construction workers face dangers to their health due to the nature of their occupation, especially those working in tropical climates (Smith et al., 2014). Physical exertion in extreme heat may lead to heat exhaustion or heat stroke, risking organ damage, loss of consciousness or death. Similarly, extreme weather events such as floods or storms also put outdoor labourers in additional danger. Ultraviolet radiation damage is also a health risk that may be increased for outdoor labourers, increasing the risk of melanoma and non-melanoma skin cancer as well as ocular cataracts, which can cause partial or full blindness (Smith et al., 2014). Another concern reported in the AR5 review is that these occupations would also have an increased risk of contracting vector-borne diseases from mosquito or tick bites. It is likely that there will be a decrease in hourly productivity without protection measures, which may conflict with economic interests and put many jobs and livelihoods in danger (Smith et al., 2014).

2.4.3 Mental Health

Extreme weather conditions can become a stressor on both those with and without mental illness. The report discusses the available evidence of an increased risk of developing mental illness for those who are not already mentally ill, when exposed to the stressful and often traumatic experiences of weather-related disasters (Smith et al., 2014). The stress and experience of weather disasters have been found to result in post-traumatic stress, generalised anxiety, depression and aggression disorders. Slow-acting events, such as gradual drought, are associated with exposure to chronic mental stress and increased occurrences of suicide (Smith et al., 2014). The European Academies report (2019) also

indicates that extreme heat can indirectly affect sleep quality and cause disturbances, which may further affect mental health when combined with these other factors.

2.4.4 Violence and Conflict

The IPCC AR5 report indicates that environmental changes and stressors may increase the likelihood of conflict and violence within communities (Smith et al., 2014). There is strong evidence that extreme heat is connected to higher levels of human aggression, crimes and anti-social behaviour, which could be exacerbated by rising temperatures and extreme heat associated with climate change (European Academies, 2019). Climate-related conflict may be caused by disputes over fertile land, fresh and clean water, food scarcity and population pressures such as overcrowding, however there are likely other complex socioeconomic and institutional factors that would affect the occurrence of violence such as poverty and lack of action from government or aid institutions. Forced migration may also have significant health impacts for the migrants as well as host countries (lack of immunisation, civil unrest and suboptimal health services), which is likely to occur in the EU (European Academies, 2019). The AR5 report concludes that violence and conflict is indirectly impacted by climate change (Smith et al., 2014).

2.5 Confidence

Both the AR4 (2007) an the AR5 (2014) reports provide confidence levels of the associated consequences of rising temperatures.

Existing Impacts and Confidence

High confidence	Alter the seasonal distribution of some allergenic pollen species. (AR4, 2007)
Medium confidence	Local changes in temperature and rainfall have altered distribution of some water-borne illnesses and disease vectors, and reduced food production for some vulnerable population. (AR5, 2014) Alter the distribution of some infectious disease vectors (AR4, 2007) Increase heatwave-related deaths. (AR4, 2007)

3. EVIDENCE OF HEALTH IMPACTS IN IRELAND

3.1 Overview

This chapter presents evidence on health impacts of climate change for Ireland using the same structure as Chapter Two. This chapter draws on the literature review for the EPA (Desmond, O'Brien and McGovern, 2017) and individual studies for Ireland. Most of the evidence for Ireland relates to studies identifying future threats to health rather than establishing past impacts.

3.2 Direct Impacts

3.2.1 Heat and cold

Mean temperatures in Ireland have increased by an average of 0.07°C per decade since 1900 (Dwyer, 2012). Ireland has seen an increase in the number of warm days while the number of cold days has concomitantly decreased (Nolan et al., 2013). As noted in Chapter Two, increases in mean temperature can be associated with increases in mortality and morbidity.

Indeed, the Review for the EPA (Desmond, O'Brien and McGovern, 2017) citied evidence for Ireland (Pascal, 2011) that a 1°C increase above 15°C in the mean temperature was associated with a 1.5% and 1.6% increase in total mortality in rural and urban areas, respectively. The search for this report shows some mixed evidence on the relationship between temperature and mortality in Ireland. A European-wide study undertaken in 2008 studied meteorological and mortality data and concluded that there was no excess mortality from excess heat in Dublin (Baccini et al., 2013). Conversely, an examination of the age-standardised daily mortality rates over the course of 17 years in Dublin found a 0.4% increase in mortality associated with an increase in temperature of 1°C (Goodman, Dockery and Clancy, 2004). These effects were restricted to the population aged over 65 years (Goodman, Dockery and Clancy, 2004). While, a more recent study found that 294 excess deaths were attributed to heatwaves that occurred between 1983 and 2006 in Ireland with the majority of these deaths occurring during the 1980s (Pascal et al., 2013).

National projections for 2050 and beyond indicate that an increase in mean annual temperatures (1-1.6°C) is projected and that all seasons could potentially become warmer (Gleeson, McGrath and Treanor, 2013; Nolan et al., 2015). Furthermore, an increase in the frequency of heatwaves has been projected (Desmond, O'Brien and McGovern, 2017). This has been identified as a threat to future health. The Review for the EPA (Desmond, O'Brien and McGovern, 2017) notes that rising temperatures in summer are likely to increase heat-

related mortalities and morbidity, especially during heatwaves (Department of Environment, Community and Local Government, 2012).

3.2.2 Floods and Storms

The international evidence (Section 2.2.2) highlights the threat to health from floods and storms. While sea levels have not been accurately measured in Ireland, UK data deemed to mirror the situation in the South of Ireland have shown a sea level rise of 1.7cm every decade since 1916 and Irish sea levels are expected to rise in all coastal areas by up to 0.8 metres by the year 2100 (Department of Communications, Climate Action and Environment, 2018).

In Ireland, data on injuries and deaths attributable to windstorm events are not formally collated. However, information on mortality during extreme events is often available in media reports. For example, Hurricane Ophelia was implicated in the deaths of three people and caused significant disruption in road infrastructure and public services and resulted in power outages in over 300,000 homes across the country (Logue et al., 2017). Disruptions in the provision of outpatient services, hospital procedures and discharges secondary to the hurricane were also reported (Health Service Executive, 2017).

3.2.3 Ultraviolet Radiation

Chapter Two noted that increases in ultraviolet radiation can be associated with increases in non-melanoma skin cancers and damage to eyes. An increase in malignant melanoma deaths related to UVR exposure has been seen across Europe, non-melanoma skin cancers caused by UVR exposure may take years or even decades to develop and eventually become fatal if left untreated (Watts et al., 2018). Caucasian populations are the most vulnerable to skin cancers, particularly those of Celtic descent. Indeed, the National Cancer Registry notes that intermittent or recreational ultraviolet radiation exposure is the main risk factor for basal cell carcinomas and malignant melanomas, while the main risk factor for squamous cell carcinomas is chronic sun exposure (National Cancer Registry Ireland, 2017). The Review for the EPA (Desmond, O'Brien and McGovern, 2017) highlighted the risk for health in Ireland noting that heatwave events and warmer, drier summers are likely to invite more people to sunbathe, probably leading to more cases of skin cancer (Department of Environment, Community and Local Government, 2012).

3.3 Ecosystem Mediated Impacts

3.3.1 Vector-borne and other infectious diseases

The international evidence (Section 2.3.1) highlights the threat of vector-borne and other infectious diseases due to climate change. There is little research on in Ireland on climate change and vector-borne and other infectious diseases. The Review for the EPA (Desmond, O'Brien and McGovern, 2017) cites international evidence showing that several vector-borne diseases (i.e. diseases spread by insects and ticks) have emerged and expanded in Europe in recent years. These include Plasmodium vivax malaria, West Nile fever, dengue fever, Chikungunya fever, leishmaniasis, Lyme disease (already present in the U.K.) and tick-borne encephalitis (UK CCRA, 2016). It highlights risks for health in Ireland as flooding may also give rise to increased cases of infectious diseases (Department of Environment, Community and Local Government, 2012).

In Ireland, warmer winters have the potential to support increased numbers and increased levels of activity of ticks, whilst also potentially extending their lifespan (Cullen, 2010). While a combination of warmer summers with reduced rainfall may have an adverse effect on tick survival, the availability of an appropriate habitat will support continued tick activity and a projected increase in forest cover will also support the survival of host animals (Cullen, 2010). A risk assessment of the potential emergence or re-emergence of indigenous vector-borne disease in Ireland that was undertaken by the HPSC in 2016 recognised the impact of climate change on potentially increasing vector density for malaria (Health Service Executive, 2016).

3.3.2 Food and water-borne infections

Chapter Two summarised international evidence on the threat of food and water-borne infections due to climate change. While little research on this for Ireland was found, research is underway to examine the links between flooding and the incidence of outbreaks of waterborne infectious diseases in Ireland (Hynds et al., 2018).

Climate change is likely to pose an increased threat of food and water-borne infections for Ireland. In Ireland, it is estimated that approximately 720,000 people obtain their drinking water from a private supply and that there are in excess of 100,000 private boreholes, dug wells and springs in use (Engineers Ireland, 2018; EPA, 2017). VTEC outbreaks have been consistently associated with private wells in Ireland (Health Protection Surveillance Centre, 2009; Health Protection Surveillance Centre, 2015; Health Protection Surveillance Centre, 2017). The storms that occurred during the winter of 2015/2016 resulted in a notable rise in the number of boil water notices issued due to Cryptosporodium contamination secondary to inadequate water treatment infrastructure (Wall, Derham and Mahony, 2016). Indeed, the Review for the EPA (Desmond, O'Brien and McGovern, 2017) notes that:

- In a future with warmer weather combined with wetter conditions food-borne diseases are likely to increase (Department of Environment, Community and Local Government, 2012) as a result of enhanced environmental conditions for bacterial growth and viral survival and inadequate food safety practices.
- Increase in rainfall and flooding may cause more water-borne disease from contamination of drinking water and inadequate cleaning practices (Department of Environment, Community and Local Government, 2012).

3.3.3 Air quality

International evidence (Section 2.3.3) points to reductions in air quality threatening health through increase in premature deaths associated with high levels of ozone exposure, increase in deaths attributed to toxic air pollution resulting from wildfires, increase in infections and reactions associated with aeroallergens. The search did not find a study for Ireland linking reductions in air quality (due to climate change) impacting on health.

It has been noted that Ireland's air quality remains good relative to other European countries but challenges to maintaining this standard include increasing levels of particulate matter (PM) and nitrogen dioxide, particularly in urban areas due to the burning of solid fuels and the high level of dependence on cars (EPA, 2018). However, the Review for the EPA (Desmond, O'Brien and McGovern, 2017) notes that higher temperatures pose significant risks to health from changes in air quality, such as increased ozone exposure discussed in Section 2.3.3 (UK CCRA, 2016). Climate change may also have implications for reactions associated with aeroallergens in Ireland. For example, evidence of an earlier budburst for birch has been observed from 1954 to 2000 which raises issues regarding the birch allergy season (Caffarra et al., 2013) and Nolan et al., (2015) project an increase in the average length of the growing season in Ireland by over 35 days by 2050 which could have implications for pollen season in Ireland (Department of Communications, Climate Action and Environment, 2018).

3.4 Institutional Mediated

3.4.1 Nutrition

Climate change has the potential to negatively impact on the quality of crops, and therefore the nutritional value of healthy foods, as noted in Chapter Two of this report. This may cause price increases for staples such as meat and vegetables, possibly leading to unhealthier diets with an excess of fatty processed foods for those with low levels of income – as a result, obesity and related diseases may increase in first-world countries (Lake et al., 2010).

3.4.2 Occupational Health

There is currently a lack of Irish-based evidence on how climate change may create hazardous conditions for outdoor workers. However, in the U.K. it has been estimated that outdoor workers (builders, forestry, agriculture) may have increased risks of developing malignant melanoma or contracting infectious diseases through water or tick exposure (Vardoulakis and Heaviside, 2012). The AR5 report also heavily details the health risks to outdoor labourers, particularly in hot countries that are close to the equator and third-world economies that rely heavily on outdoor labour, such as India (Smith et al., 2014).

3.4.3 Mental Health

The EPA report (Desmond, O'Brien and McGovern, 2017) provides evidence of extreme weather events such as floods and storms having some potential to affect mental health (Berry et al., 2010). This effect can be seen during flooding in Wales and England, where residents who had their homes flooded had between 2-5 times higher rates of psychological distress, depression and anxiety symptoms than those who did not experience flooding in their homes (Paranjothy et al., 2011). As sea levels are predicted to rise, along with the frequency of extreme storms and flooding, the mental stress of those affected by such weather events should be considered a potential indirect consequence of climate change in Ireland.

3.4.5 Violence and Conflict

As discussed in Chapter Two, the possibility of violence and conflict has the potential to increase with rapid climate change, including disputes over fertile land, access to clean water, overpopulation and climate refugees/increased migration to less-affected countries. Conflict could also occur over disputes of access to food, shelter or water during extreme weather events. Forced migration may also affect the health of the national and migrant population, in areas of immunisation, introduction of new diseases, possible civil unrest or unmet health needs (European Academies, 2019).

4. CO-BENEFITS: HEALTH BENEFITS FROM CLIMATE ACTION

4.1 Overview

Both the IPCC AR5 report (Smith et al., 2014) and the COP24 report (WHO, 2018) summarise the health gains that can occur from actions to mitigate climate change or co-benefits. Co-benefits have been defined as "positive effects on human health that arise from interventions to reduce emissions of those climate-altering pollutants (CAPs) that warm the planet or vice versa" IPCC AR5 report (Smith et al., 2014). The main areas for climate action identified for health benefits are:

- Increasing consumption of diets with low greenhouse gas emissions and improving agriculture and good waste practices.
- Reducing co-pollutants from household solid fuel combustion, better lighting and application of passive design principles.
- Reducing greenhouse gases and associated co-pollutants from industrial sources.
- Increasing energy efficiency, reducing demand for fossil fuels and increasing demand renewable energy.
- Increasing green areas in urban spaces.
- Increasing active travel, modifications to public transport and to the built environment.
- Reducing unmet need for contraception and for family planning services.
- Reducing emissions from deforestation and improving forest management practices.

These methods of climate harm reduction as well as their additional co-benefits to human health captured by AR5 report (Smith et al., 2014) are summarised below, alongside relevant tables from the COP24 report (WHO, 2018) which focuses on health gains of climate change mitigation across key sectors.

4.2 Diets with Low Green-House Emissions and Agriculture

The IPCC AR5 report (Smith et al., 2014) notes that healthy low greenhouse gas emission diets which can have beneficial effects on a range of health outcomes. This can include reduction of meat products related to ruminants (i.e. cows, sheep, deer etc). The reduction of ruminant-related products could also reduce potential faecal biohazards, such as water contamination and associated complications. According to the Institute of Public Health (Wilde, 2010), agriculture is the single largest contributor to Irish greenhouse gases emissions at 27.3% of the total emissions, indicating that mitigation action in this sector would have a significant impact.

Benefits for climate: Reductions in CO2 and CH4 emissions from energy-intensive livestock systems.

Health benefits: Reduced dietary saturated fats in some populations (particularly from ruminants) and replacement by plant sources, associated with decreased risk of (ischemic) heart disease, stroke, colorectal cancer (processed meat consumption). Increased fruit and vegetable consumption can reduce risk of chronic diseases. Reduced methane emissions due to a decreased demand for ruminant meat products would reduce tropospheric ozone.

The IPCC AR5 report (Smith et al., 2014) citied a number of reports since AR4 to support the above benefits Hooper et al., 2012; Pan et al., 2012; Xu et al., 2012; Jakszyn et al., 2011, Friel et al., 2009; Sinha et al., 2009; Smith and Balakrishnan, 2009; McMichael et al., 2007.
COP24 (WHO, 2018) also stresses the benefits of promotion of healthy diets low in emissions but also discussed reducing open burning of agricultural fields and reducing food waste.

Agriculture			
Mitigation activity	**Main health benefits**	**Health benefit[1]**	**Climate pollutants[2]**
*Promotion of healthy diets low in red meat and processed meats and rich in plant-based foods	▪ Less crop damage and extreme weather ▪ Reduced obesity and diet-related non-communicable diseases	High	High
*Reduced food waste	▪ Less crop damage and extreme weather ▪ Reduced food insecurity/undernutrition	Medium-high	Low-medium
Reduced open burning of agricultural fields	▪ Improved air quality ▪ Less crop damage and extreme weather	Medium	Low-medium
[1] Aggregate level of potential health benefit. [2] Certainty of major effect short-lived climate pollutants			
*Particularly relevant to Ireland			
Source: Derived from COP24 (WHO, 2018) which is based on WHO (2015)			

4.3 Household Solid Fuel Combustion and Building Design

The IPCC AR5 report (Smith et al., 2014) stresses the benefits of the reduction of co-pollutants from household solid fuel combustion. It notes that the goal of reducing climate-altering pollutants (CAPs) can be used to reduce harm and contribution to climate change, and reduction can also have significant and beneficial impacts on human health. These benefits of reducing household solid fuel consumption are summarised below.

Climate benefits: Reduces CAP emissions associated with household solid fuel use – including CO2, CO, black carbon and CH4.

Health benefits: This adaptation measure can potentially reduce exposure to pollutants commonly associated with disease, chronic and acute respiratory illnesses, lung cancer, low birth weight, stillbirths and tuberculosis. There is also a potential to reduce negative health effects associated with fuel poverty, which can affect especially vulnerable groups such as children, single parents, the elderly and the unemployed (Wilde, 2010).

The IPCC AR5 report cites a number of references since AR4 - Anenberg et al., 2012; Po et al., 2011; Lefohn et al., 2010; Venkataraman et al., 2010; World Health Organisation Regional Office for Europe, 2010; Wilkinson et al., 2009; Bell et al., 2008; Smith et al., 2008. The COP24 report (WHO, 2018) summarises evidence on co-benefits from a more recent WHO (2015) report as shown below.

Household air pollution and building design*			
Mitigation activity	**Main health benefits**	**Health benefit[1]**	**Climate pollutants[2]**
Low-emission stoves and/or reducing solid fuel use	▪ Improved air quality ▪ Less crop damage and extreme weather ▪ Less violence and risk of injury during fuel collection ▪ Fewer burns	High	Medium-high
Passive design principles	▪ Thermal regulation ▪ Improved indoor air quality	Medium	Low-medium
[1] Aggregate level of potential health benefit. [2] Certainty of major effect short-lived climate pollutants			
Source: Derived from COP24 (WHO, 2018) which is based on WHO (2015)			
***Data for third world countries on kerosene lamps omitted.			

4.4 Pollution from Industry

The IPCC AR5 report (Smith et al., 2014) identifies reduction of greenhouse gases and associated co-pollutants from industrial sources, such as power plants and landfills, by more efficient generation or substitution of low carbon alternatives. Impacts of this are summarised below.

Climate benefits: Reductions in emissions of CO2, black carbon, CO, CH4 and other CAPs.

Health benefits: Emission caps on industry emissions would entail reductions in health-damaging co-pollutant emissions, decreased exposures to outdoor air pollution and could

reduce risks of cardiovascular disease, chronic and acute respiratory illnesses, lung cancer and premature birth.

The IPCC AR5 report cites a relatively large number of reports since AR4 - West et al., 2013; Shindell et al., 2012; West et al., 2012; Shonkoff et al., 2011; Nemet et al., 2010; Rive and Aunan, 2010; Apsimon et al., 2009; Jacobson et al., 2009; Bell et al., 2008. The table below shows the benefits identified by COP24 report (WHO, 2018) which is based on WHO (2015).

Industry*			
Mitigation activity	**Main health benefits**	**Health benefit[1]**	**Climate pollutants[2]**
Control of fugitive emissions from fossil fuel industry	▪ Improved air quality ▪ Less crop damage and extreme weather	Low	High
[1] Aggregate level of potential health benefit. [2] Certainty of major effect short-lived climate pollutants			
Source: Derived from COP24 (WHO, 2018) which is based on WHO (2015)			
*Data relevant to third-world countries omitted (such as coke ovens and brick kilns).			

4.5 Energy Efficiency and Supply

Energy efficiency is highlighted by the IPCC AR5 report (Smith et al., 2014) which notes that reducing the demand for fossil fuels and creating demand for renewable energy (such as solar, electric and nuclear power) can potentially reduce emissions of CAPs, which will have substantial positive effects on human health as well as the climate.

Climate benefits: Reductions in emission of CAPs due to decreases to fuel consumption.

Health benefits: Reductions in fuel demand potentially can reduce emissions of CAPs associated with fuel combustion and subsequent exposures to pollutants that are known to be damaging to health.

The IPCC AR5 report (Smith et al., 2014) citied two reports from 2009 (Markandya et al., 2009; Wilkinson et al., 2009). While the COP24 report (WHO, 2018) focuses on benefits in relation to energy supply and electricity as shown below.

Energy supply, electricity			
Mitigation activity	**Main health benefits**	**Health benefit[1]**	**Climate pollutants[2]**
Switch from fossil fuels to renewable energy for large-scale power production	▪ Improved air quality ▪ Less crop damage and extreme weather ▪ Fewer occupational injuries	High (coal and oil) Low-medium (gas)	Low
Replacement with or supplementation of small-scale diesel generators with renewable energy	▪ Improved air quality ▪ Less crop damage and extreme weather ▪ Reduced noise	Low-medium	Low-medium
Control of fugitive emissions from fossil fuel industry	▪ Improved air quality ▪ Less crop damage and extreme weather	Low	High
[1] Aggregate level of potential health benefit. [2] Certainty of major effect short-lived climate pollutants			
Source: Derived from COP24 (WHO, 2018) which is based on WHO (2015)			

4.6 Urban Green Spaces

It is apparent in the IPCC AR5 that Europe has become increasingly urbanised, with fewer green spaces within densely populated areas (Smith et al., 2014). There is an observed link between ecosystems, the presence of greenery and the mental health of the population, indicating that the presence of maintained and aesthetically pleasing green areas in urban centres plays a role in improving the physical and mental health of urban residents (Smith et al., 2014).

Climate benefits: Reduces atmospheric CO2, via carbon sequestration in plant tissue and soil.

Health benefits: Reduced temperatures and heat island effects; reduced noise; enhanced safety; psychological benefits; better self-perceived health status.

The IPCC AR5 report (Smith et al., 2014) citied the following reports to support the above claims: Mitchell and Popham (2007); Babey et al. (2008); Maas et al (2009); van den Berg et al. (2010); van Dillen et al. (2011).

4.7 Active Travel, Transport and the Build Environment

The IPCC AR5 report (Smith et al., 2014) identifies the benefits of increasing active travel and reducing in pollution due to the modifications to the built environment, including better access to public transport and higher density of urban settlements. It notes that increasing accessibility for safe active travel (i.e. walking, biking) as well as mass, rapid public transport will have immediate and significant impacts on the climate, such as air quality as well as human health in areas of physical exercise, obesity and a potential reduction in road traffic accidents – see below for a summary.

Climate benefits: Reductions of CAP emissions associated with vehicle transport; replacing existing vehicles with lower emission vehicles could reduce air pollution.

Health benefits: Increased physical activity; reduced obesity; reduced non-communicable disease burden, health service costs averted; improved mental health; reduced exposure to air pollution; increased local access to essential services, including food stores; enhanced safety.

The IPCC AR5 report (Smith et al., 2014) citied a number of reports since AR4 to support the above benefits: Jensen et al., 2013; Woodcock et al., 2013; Durand et al., 2011; McCormack and Shiell, 2011; Casagrande et al., 2009; Grabow et al., 2011; Jarrett et al., 2009; Rundle et al., 2009; Woodcock et al., 2009; Kaczynski and Henderson, 2008; Babey et al., 2007 - while the COP24 report (WHO, 2018) focuses on benefits in relation to transport mitigations which includes active travel but also mitigation activity aimed emissions and efficiency.

Transport			
Mitigation activity	**Main health benefits**	**Health benefit[1]**	**Climate pollutants[2]**
Support for active (and rapid mass) transport	▪ Improved air quality ▪ Less crop damage and extreme weather ▪ Increased physical activity ▪ Fewer road traffic injuries	High	High
Ultra-low-sulphur diesel with diesel particle filters	▪ Improved air quality ▪ Less crop damage and extreme weather	Medium-high	Medium
Higher standards for vehicle emissions and efficiency	▪ Improved air quality ▪ Less crop damage and extreme weather	High	Medium-high
[1] Aggregate level of potential health benefit. [2] Certainty of major effect short-lived climate pollutants			
Source: Derived from COP24 (WHO, 2018) which is based on WHO (2015)			

4.8 Unmet Need for Contraception and Family Planning

The IPCC AR5 report (Smith et al., 2014) refers to research showing that slowing population growth through lowering fertility, as might be achieved by increasing access to family planning and meeting unmet need for reproductive health services, has been associated with benefits for the climate and health. It also notes that this is important not only in poor countries, however, but also some rich ones where there is unmet need for reproductive health services. This may also alter the levels of climate refugees or emigrants in later stages, reducing potential health effects associated with migration as discussed in Section 3.4.5.

Climate benefits: Potentially slower growth of energy consumption and related CAP emissions; less impact on land use change, etc.

Health benefits: Lower child and maternal mortality from increased birth intervals and shifts in maternal age.

The IPCC AR5 report (Smith et al., 2014) cites the following: Kozuki et al., 2013; Potts and Henderson, 2012; Diamond-Smith and Potts, 2011; O'Neill et al., 2010; Gribble et al., 2009; Prata, 2009; Tsui et al., 2007.

4.9 Forestation and Deforestation

The IPCC AR5 report (Smith et al., 2014) discusses how carbon sequestration (removing CO^2 from the atmosphere via plant tissue) can reduce emissions caused by deforestation, thereby reducing the amount of CO^2 in the atmosphere which contributes to rising temperatures and climate change. Carbon sequestration has indirect health benefits, as this industry may provide jobs for forested areas, improving livelihoods and reducing poverty (Smith et al., 2014).

Climate benefits: Reduces emissions of CAPs and promotes carbon sequestration through reducing emissions from deforestation and degradation.

Health benefits: Poverty alleviation and livelihood/job generation through sale of Clean Development Mechanism and voluntary market credits. Ameliorate declines in production or competitiveness in rural communities.

The AR5 (Smith et al., 2014) cites the following articles as supporting evidence: Holmes, 2010; Ezzine-de-Blas et al., 2011.

4.10 Confidence

The Executive Summary of AR5 notes that there are opportunities to achieve co-benefits from actions that reduce emissions of warming CAPs and at the same time improve health. It attaches a level of confidence to these actions as shown below.

Very high confidence	Reducing local emissions of health-damaging and climate-altering air pollutants from energy systems, through improved energy efficiency, and a shift to cleaner energy sources.
High confidence	Designing transport systems that promote active transport and reduce use of motorised vehicles, leading to lower emissions of CAPs and better health through improved air quality and greater physical activity.
Medium confidence	Providing access to reproductive health services (including modern family planning) to improve child and maternal health through birth spacing and reduce population growth, energy use, and consequent CAP emissions over time. Shifting consumption away from animal products, especially from ruminant sources, in high-meat-consumption societies toward less CAP intensive healthy diets.

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Appendix A

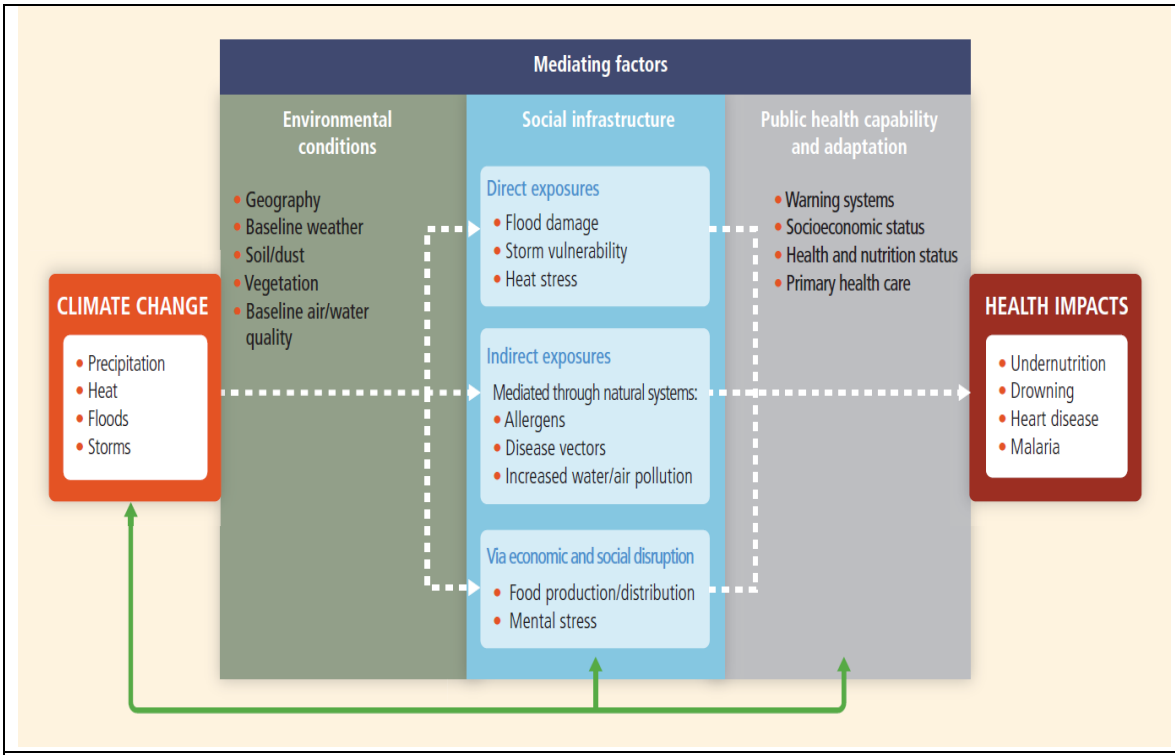
Overview

The four conceptual frameworks for understanding how climate change can impact on health that were identified in the literature search are described here.

Climate Change, Three Exposure Pathways and Mediating Factors

The IPCC AR5 Report (Smith et al., 2014) uses the conceptual diagram below. It focuses on three primary exposure pathways by which climate change affects health: directly through weather variables such as heat and storms; indirectly through natural systems such as disease vectors; and pathways heavily mediated through human systems such as undernutrition.

Climate Change, Three Exposure Pathways, Mediating Factors and Health Impacts



Source: IPCC AR5 (Smith et al., 2014)

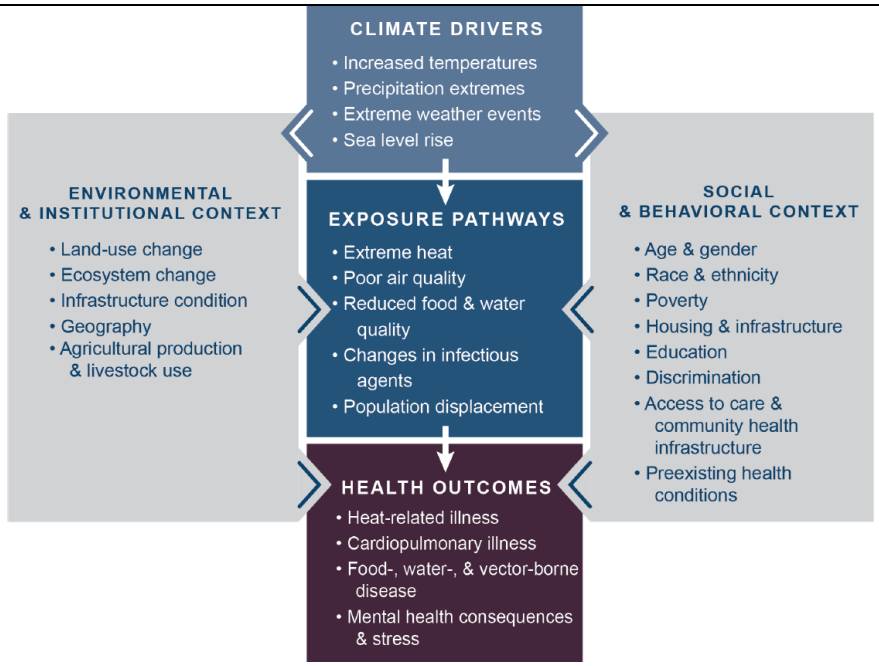
The green box indicates the moderating influences of local environmental conditions on how climate change exposure pathways are manifest in a particular population. While the grey box indicates that the extent to which exposures translate to actual health burden is moderated by such factors as background public health and socioeconomic conditions, and adaptation measures. The green arrows at the bottom indicate that there may be feedback

mechanisms, positive or negative, between societal infrastructure, public health, and adaptation measures and climate change itself.

Exposure Pathways and Context Approach

The Fourth National Climate Assessment Report (Ebi et al., 2018) uses the conceptual diagram provided in The Scientific Assessment Report (USGCRP, 2016) shown below.

Climate Change, Exposure Pathways and Health Outcomes



Source: The Scientific Assessment Report (Balbus et al., 2016)

It argues that a useful approach to understand how climate change affects health is to consider specific exposure pathways and how they can lead to human disease. It borrows the concept of exposure pathways from its use in chemical risk assessment to describe the main routes by which climate change affects health. Exposure is contact between a person and one or more biological, psychosocial, chemical, or physical stressors, including stressors affected by climate change. The centre of the conceptual diagram illustrating the exposure pathways by which climate change affects human health.

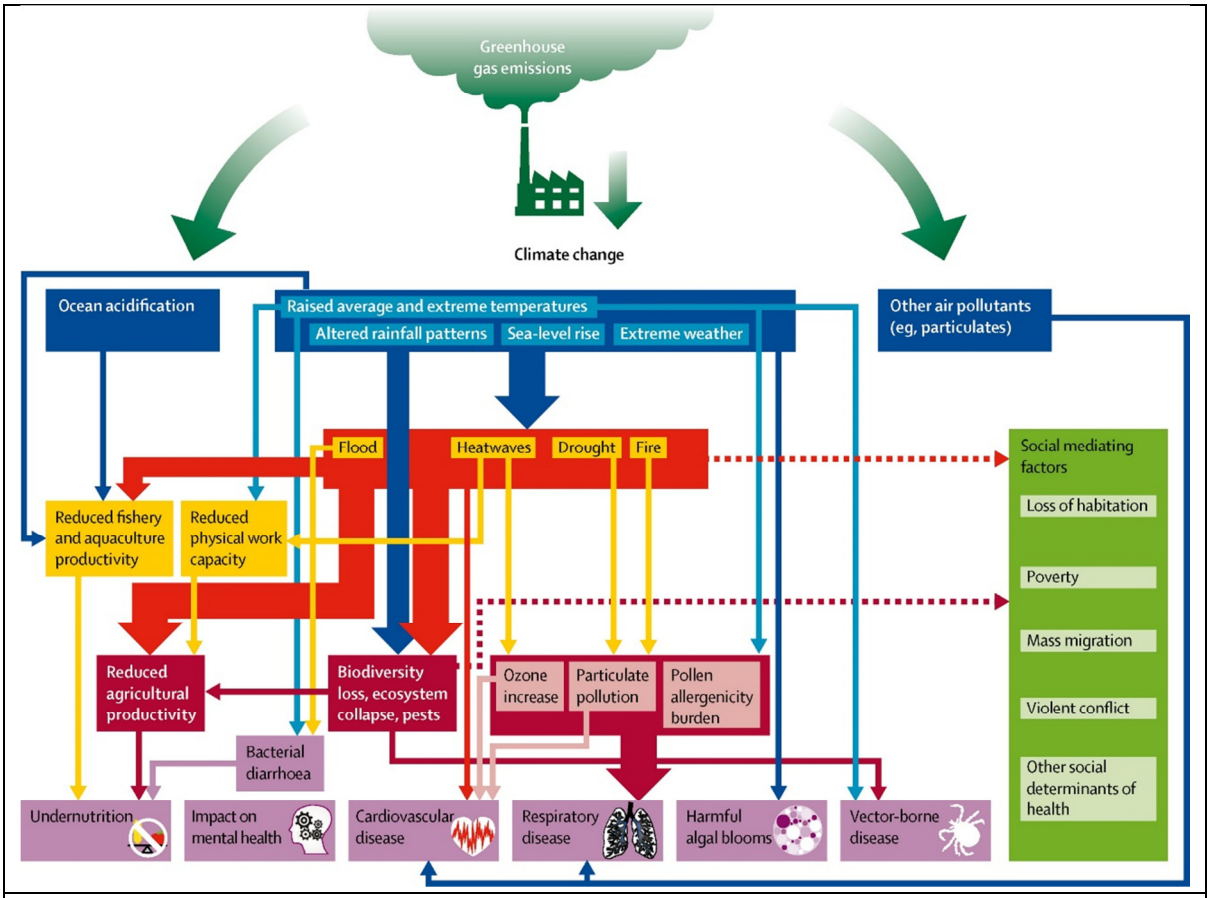
The extent to which climate change could alter the burden of disease in any location at any point in time will depend not just on the magnitude of local climate change but also on individual and population vulnerability, exposure to changing weather patterns, and capacity to manage risks, which may also be affected by climate change. The grey side boxes show that exposure pathways exist within the context of other factors that positively or negatively influence health outcomes, namely factors that influence vulnerability for individuals which include social determinants of health and behavioural choices, and factors

that influence vulnerability at larger scales, such as natural and built environments, governance and management, and institutions.

The Pathways between Climate Change and Human Health

The Lancet Countdown Report (Watts et al., 2018) notes that "a rapidly changing climate has dire implications for every aspect of human life, exposing vulnerable populations to extremes of weather, altering patterns of infectious disease, and compromising food security, safe drinking water, and clean air". It puts forth the conceptual framework below.

The Pathways between Climate Change and Human Health

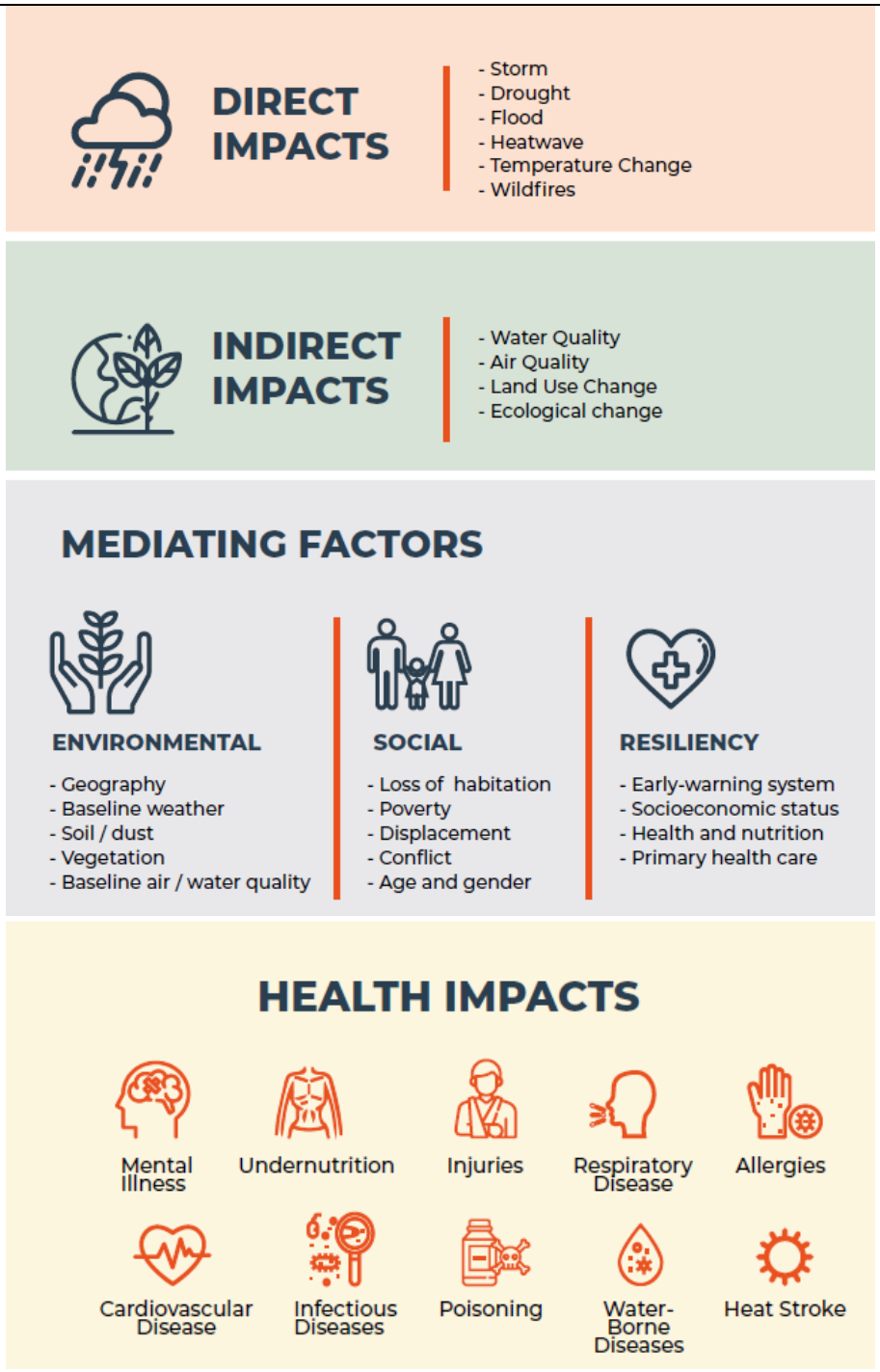


Source: The Lancet Countdown (Watts et al., 2018)

Direct and indirect links between climate change and health

Finally, the COP24 Special Report conceptualisation shows that climate change impacts health both directly and indirectly, but is strongly mediated by environmental, social and public health determinants.

The Pathways between Climate Change and Human Health



Source: COP24 Special Report (WHO 2018)