Challenges and gaps in assessing impacts of climate change on health in rural areas

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Background paper for Expert Group Meeting on Eradicating Rural Poverty to Implement the 2030 Agenda for Sustainable Development

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Executive summary

Climate change is expected to cause significant harms to population health. On the other hand, ongoing progress towards achieving the Sustainable Development Goals (SDGs) will greatly improve health, particularly of those currently living in poverty. The mutually supportive and contradictory interactions between climate change, actions to mitigate and adapt to it, progress towards the SDGs, poverty, and population health pose major challenges to assessing (and reducing) the potential the impacts of climate change on the health of rural populations.

This background paper gives an overview of these challenges from the perspective of population health research and modelling. We begin by briefly outlining the relations between climate change, population health and the SDGs. We then focus on three sets of challenges faced when assessing the health impacts of climate change in rural areas.

First set of challenges: Untangling the relations between climate change, sustainable development, poverty and health

> ***Challenge 1.1:*** *The health impact community, in collaboration with other disciplines, should consider developing health impact assessments that specifically aim to consider the interactions between progress on the Paris Agreement (as well as more pessimistic climate futures) and the 2030 Agenda, in order to assess the health implications of future pathways, with a particular focus on groups who may most benefit or be most harmed.*

> ***Challenge 1.2:*** *As well as further developing assessments that predict the impacts of poverty on health, additional assessments based on specific causal mechanisms by which poverty affects health may help show which types of actions to reduce poverty are likely to have the greatest health benefits, thus also reducing causal feedback from ill health to poverty.*

Second set of challenges: Representing rural areas in scenario-based climate-health impact assessments

> ***Challenge 2.1:*** *Health researchers and modellers should attempt to better represent development in assessments (including its uneven distribution), by rapidly adopting newly available SSP scenario data.*

> ***Challenge 2.2:*** *Health researchers and modellers should explore means of representing the qualities of rural areas that are likely to shape the climate-health relation, perhaps by developing typologies in order to balance real-world heterogeneity and model parsimony.*

> ***Challenge 2.3:*** *The climate change impacts community could consider developing socioeconomic scenarios that assume structural conditions support the development of vibrant rural communities, where agriculture remains a significant source of employment, perhaps via agroecology.*

Third set of challenges: Assessing health impacts in scenario-based assessments

> ***Challenge 3.1:*** *When developing empirically-based health assessment models, researchers should critically assess the quality of apparently robust historical data to avoid drawing misleading conclusion about health impacts and policy priorities; this may be particularly pertinent to many rural areas where data may be based on extrapolations.*

> ***Challenge 3.2:*** *Given the inherent complexity of the relations between health, climate change, and development, health researchers should consider (i) consciously adopting an 'open' approach to science (by, for example, exploring unforeseen turns in results), and (ii) combining insights from quantitative predictive models with insights from qualitative explanatory models, the latter being potentially useful in rural areas with limited data availability.*

Challenge 3.3: *The differences between futures with lower and higher carbon emissions do not begin to vary widely until around the 2050s; in order to assess threats to progress made under the SDGs, and to help ensure ongoing progress, it is necessary to develop detailed socioeconomic scenarios that extend beyond 2030 and represent the most vulnerable groups, and to utilise these scenarios in health assessments.*

Challenge 3.4: *New interdisciplinary approaches to health impact assessments could be developed jointly with specialists from other disciplines to allow the investigation of processes shaping health that may be systematically excluded from existing multidisciplinary models, particularly those processes that may unevenly impact on poorer communities.*

Challenge 3.5: *Global-level assessments potentially offer different insights than those conducted at local-level; new insights into health in rural areas may be gained by attempting to incorporate relevant global processes – particularly those that influence patterns of poverty and inequality - into global-level assessments.*

Challenge 3.6: *In health assessments of climate-related disasters, as well using approaches that view people as being vulnerable to hazards, consideration should be given to adopting alternative approaches that more firmly locate the causation of vulnerability in society with hazards being one cause amongst many; such an approach may allow better assessment of the interactions between future climate and development pathways, particularly the implications for the most vulnerable populations.*

It has been argued elsewhere that because poverty carries the moral implication that something should be done about it, the study of it can only be justified if it influences attitudes and actions. Climate-health assessments may potentially contribute to both these, partly by tying the above challenges together into two general strategies. Firstly, health assessments that pay equal attention to both climate change and sustainable development should be developed, and these should specifically include a focus on rural areas. Second, alongside quantitative assessments that predict impacts (thus identifying potential priorities), assessments that seek to explain should also be developed. The latter may provide insights into causal mechanisms and identify the benefits and harms of various interventions

Abbreviations

AR5: Fifth Assessment Report (of the IPCC)
CRDPs: Climate-Resilient Development Pathways
GBD: Global Burden of Disease
GDP: Gross Domestic Product
IPCC: Intergovernmental Panel on Climate Change
MPI: Multi-dimensional Poverty Index
SDGs: Sustainable Development Goals

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Background

Introduction

Climate change is expected to cause significant harms to population health, with poor and disenfranchised groups facing the greatest risks (Smith et al., 2014). On the other hand, ongoing progress towards achieving the Sustainable Development Goals (SDGs) will greatly improve health, particularly of those currently living in poverty (Dzebo et al., 2018). These two processes will interact, with climate change potentially impairing development and its health benefits (Watts et al., 2018) and development potentially bringing both synergies and trade-offs for climate change mitigation and adaptation (Roy et al., 2018).

Both climate change and progress on the SDGs will have distinct impacts on the health of rural populations (Dasgupta, 2014, De La O Campos et al., 2018). Presently, rural communities bear a significant proportion of the global burden of disease and are home to around 80% of the world's population living in extreme poverty (De La O Campos et al., 2018), making them particularly vulnerable to climate change. Further, ill health may pull people and households into poverty or prevent them from moving out of it (Hallegatte and Rozenberg, 2017) and, conversely, poverty may contribute to ill health in rural populations (e.g. Lloyd et al., 2018).

The mutually supportive and contradictory interactions between climate change, actions to mitigate and adapt to it, progress towards the SDGs, poverty, and population health pose major challenges to assessing (and reducing) the potential the impacts of climate change on the health of rural populations. This background paper gives an overview of these challenges from the perspective of population health research and modelling. We note that this paper does not set out to provide a comprehensive review of the current state of knowledge; rather, we draw on our experience of assessing the impacts of climate change on health – which is largely based in scenario-based modelling - to identify more widely applicable challenges and gaps.

The paper is structured as follows. The remainder of this section briefly outlines the relations between climate change, population health and the SDGs. The subsequent sections focus on three sets of challenges faced when assessing the health impacts of climate change in rural areas, broadly moving from the general to the more particular. Firstly, the challenges in untangling the mutually conditioning relations between climate change and development, and between poverty[1] and health. Secondly, the challenge of representing the distinct qualities of rural areas in climate-health impact assessments. Thirdly, we discuss challenges when assessing health impacts in scenario-based modelling[2]. Finally, we tie the challenges together to identify how gaps may be filled to develop policy-relevant research and modelling.

Climate change and population health

Patterns of population health may be characterised as 'structured chance' (Krieger, 2012). That is, within a given population, any individual's risk of poor health is partly driven by chance, while overall population-level rates of poor health are structured by contextual factors and differ systematically across populations. Climate change, which occurs at large spatial scales, changes these structural conditions and - in combination with other contextual factors - affects risk in entire populations, albeit

[1] In this paper, we do not attempt to address issues around how poverty is conceptualized or operationalised.
[2] We note that in this document, rather than examining specific health impacts of climate change, we instead aim to identify general challenges that are applicable across a range of health impacts.

the distribution of risk is likely to vary by sub-group (McMichael et al., 2017). For rural areas, the combinations of particular contextual factors and climate change are likely to pose a different set of risks than in urban areas.

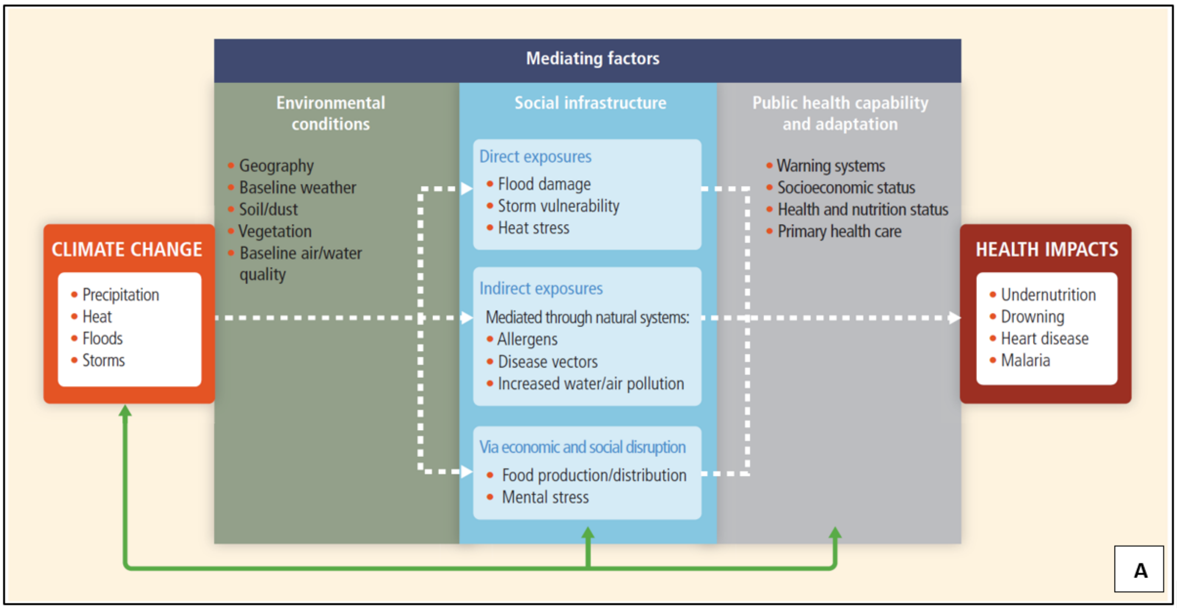
There are three general routes from climate change to population health (Figure 1, Panel A). Direct routes, for instance via increased heat waves; indirect routes via ecosystem changes, which may, for example, alter the range of disease-carrying vectors; and, indirect routes through impacts on societal systems, such as parts of the global-food system. As these routes become more complex, a wider array of non-climate factors come into play. Underlining this, McMichael (2017) warned against "climate determinism" when assessing future health under climate change, with climate instead being seen as a contributor or amplifier. This suggests that to understand potential patterns of health risks, as well as steps that may be taken to reduce vulnerability, it is necessary to focus on both climatic and social conditions.

The major impacts of climate change on health (compared to no climate change) – based on the scenarios assessed in the Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report (AR5) – are summarized in Figure 1, Panel B.

The health impacts of climate change are already being increasingly felt via a wide range of exposures and outcomes, as tracked, for example, by the "Lancet Countdown" (Watts et al., 2018) (see Box 1). Many, if not most, of these impacts are likely to be significantly affecting poor rural communities (e.g. agricultural labour loss due to heat stress; food security and undernutrition due to crop yield reduction; extreme weather impacts on livelihoods). However, given the scope of the Lancet Countdown (which aims to develop a global monitoring system), but also "… the need for more detailed, national-level, and local-level analyses", specific effects on rural and/or poor communities are not reported.

Under the Paris Agreement (United Nations, 2015a) attention has been drawn to the implications of limiting future warming to 1.5ºC or 2ºC[3]. The IPCC recently assessed the potential health impacts in such futures based on papers published since 2008 (Hoegh-Guldberg et al., 2018). Overall, it was concluded that 2°C warming poses greater risks to human health than warming of 1.5°C, with the risks often varying regionally. The authors reported, "There is very high confidence that each additional unit of warming could increase heat-related morbidity and mortality, and that adaptation would reduce the magnitude of impacts. There is high confidence that ozone-related mortality could increase if precursor emissions remain the same, and that higher temperatures could affect the transmission of some infectious diseases, with increases and decreases projected depending on the disease (e.g., malaria, dengue fever, West Nile virus and Lyme disease), region and degree of temperature change." An associated paper (Ebi et al., 2018) also reported that, "Three studies compared health risks associated with food insecurity at 1.5ºC and 2ºC, concluding that risks are higher at 2ºC." The authors noted that there was a lack of assessments that specifically aimed to estimate health impacts for a given temperature change, with estimates instead made for a given future time-slice. Using these latter estimates to derive temperature change-related impacts compromises the potential to assess the combined impacts of climate and development on health under which 1.5ºC and 2ºC of warming may be reached.

[3] This is relative to pre-industrial condition, defined as 1850-1900. At present, warming is about 1º (Ebi et al., 2018).



- Greater risk of injury, disease, and death due to more intense heat waves and fires (very high confidence)
- Increased risk of undernutrition resulting from diminished food production in poor regions (high confidence)
- Consequences for health of lost work capacity and reduced labour productivity in vulnerable populations (high confidence)
- Increased risks of food-, water-borne diseases (very high confidence) and vector-borne diseases (medium confidence)
- Modest reductions in cold-related mortality and morbidity in some areas due to fewer cold extremes (low confidence), geographical shifts in food production, and reduced capacity of disease-carrying vectors due to exceedance of thermal thresholds (medium confidence). These positive effects will be increasingly outweighed, worldwide, by the magnitude and severity of the negative effects of climate change (high confidence)

B

Figure 1, Panel A: The three general routes from climate change to population health, showing climate change and examples of its effects on weather conditions on the left, the three routes from climate to health in the centre, and examples of health impacts on the right. See text and original caption[4] for further details. Panel B: The major changes in ill health compared to no climate change as report in IPCC AR5.

<u>Source</u>: Smith et al. (2014)

Further, in the above, rural-specific impacts were not reported. It was noted that since IPCC AR5, there has been limited research on climate impacts on livelihoods, poverty and rural areas. These areas, along with research on health in the context socioeconomic conditions and climate change at 1.5^{o}C – i.e. precisely the focuses of this background document - were highlighted as areas with gaps in understanding (Hoegh-Guldberg et al., 2018).

[4] The original caption for Panel A is: “Figure 11-1 Conceptual diagram showing 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. The green box indicates the moderating influences of local environmental conditions on how climate change exposure pathways are manifest in a particular population. The gray box indicates that the extent to which the three categories of exposure 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. As discussed later in the chapter, for example, some measures to improve health also reduce emissions of climate-altering pollutants, thus reducing the extent and/or pace of climate change as well as improving local health (courtesy of E. Garcia, UC Berkeley). The examples are indicative.”

Box 1: An overview of the health-related indicators of climate change impacts, exposures, and vulnerability adopted by the "Lancet Countdown", and the headline findings.

Vulnerability to the heat-related risks of climate change: rising ambient temperatures place vulnerable populations at increased risks across all regions. Population in Europe and the East Mediterranean are particularly at risk, with 42% and 43% of their populations older than 65 years vulnerable to heat exposure
Health effects of temperature change: the mean global temperature change to which humans are exposed is more than double the global average change, with temperatures rising 0.8°C versus 0.3°C (Population weighted versus area weighted summer warming in 2017 relative to the 1986–2005 average).
Health effects of heatwaves: in 2017, an additional 157 million heatwave exposure events occurred globally, representing an increase of 18 million additional exposure event compared with 2016.
Change in labour capacity: in 2017, 153 billion hours of labour (3.4 billion weeks of work) were lost, an increase of 62 billion hours lost relative to 2000.
Health effects of extremes in precipitation (floods and drought): changes in extreme precipitation exhibit clear regional trends, with South America and southeast Asia among the regions most exposed to flood and drought.
Lethality of weather-related disasters: annual frequencies of floods and extreme temperature events have increased since 1990, with no clear upward or downward trend in the lethality of these events.
Global health trend in climate-sensitive diseases: although global health and development interventions have resulted in some impressive improvements in human health and wellbeing, mortality from two particularly climate-sensitive diseases, dengue fever and malignant skin melanoma, is still rising in regions most susceptible to both diseases.
Climate-sensitive infectious diseases: in 2016, global vectorial capacity for the transmission of dengue virus was the highest on record, rising to 9.1% above the 1950s baseline for *A aegypti* and 11.1% above the baseline for *A albopictus.*
Food security and undernutrition: (a) Terrestrial food security and undernutrition: 30 countries are experiencing downward trends in crop yields, reversing a decade-long trend that had previously seen global improvement. Yield potential is estimate to be declining in every region, as measured by accumulated thermal time; (b) Marine food security and undernutrition: sea surface temperature has risen substantially in 16 of 21 key fishing basins and threats to marine primary productivity being expected to follow.
Migration and population displacement: climate change is the sole contributing factor for thousands of people deciding to

Source: Adapted from Watts et al. (2018).

The SDGs, climate change, and population health

SDG 3 is specifically about health, but there are more than 50 health-related SDG targets across at least 10 goals (WHO, 2018). In general, progress is being made, but for some indicators, the required rates of change to meet the targets are far higher than the pace of progress achieved in any country in the recent past: these include child malnutrition, several infectious diseases including malaria and neglected tropical diseases, and violence associated with conflict (GBD 2017 SDG Collaborators, 2018).

Climate change poses a threat to the achievement of many of the health-related SDG targets; Table 1 shows the health-related SDG targets that climate change may affect. However, the interactions between climate change and the SDGs are complex, posing difficulties for health impact assessments. We discus this in the next section.

Table 1 Health-related SDGs that may be directly impacted by climate change

Goal/Targets	Indicator	Potential impact of climate change on health
1. End poverty in all its forms everywhere 1.1 By 2030, eradicate extreme poverty for all people everywhere, currently measured as people living on less than $1.25 a day 1.5 By 2030, build the resilience of the poor and those in vulnerable situations and reduce their exposure and vulnerability to climate-related extreme events and other economic, social and environmental shocks and disasters	1.1.1 Proportion of population below the international poverty line, by sex, age, employment status and geographical location (urban/rural) 1.5.1 Number of deaths, missing persons and persons affected by disaster per 100,000 people	Climate change is a major threat to poverty reduction, via damage to housing and infrastructure from extreme events, worsened food and water insecurity, loss of livelihoods, reduced ability to work through heat and diverse effects on health. Climate change could force more than 3 million to 16 million people into extreme poverty by 2030, mostly through impacts on agriculture and food prices (Hallegatte et al., 2016, Hallegatte and Rozenberg, 2017). With warming of 1.5°C between 24–357 million people were exposed to multi-sector climate risks and vulnerable to poverty; four times more people were 2^{o} of warming (Roy et al., 2018). Number of deaths, missing persons and persons affected by disasters will tend to increase. Building resilience will be difficult to achieve in the face of increasing frequency and/or severity of climate related disasters (heatwaves, fires, droughts, storms, sea level rise, floods) It has been estimated that 3546–4508 million people would be exposed to heat waves with warming of $1.5^{o}C$ (Roy et al., 2018).
2. End hunger, achieve food security and improved nutrition and promote sustainable agriculture 2.2 By 2030, end all forms of malnutrition, including achieving, by 2025, the internationally agreed targets on stunting and wasting in children under 5 years of age, and address the nutritional needs of adolescent girls, pregnant and lactating women and older persons	2.2.1 Prevalence of stunting (height for age <-2 standard deviation from the median of the World Health Organization (WHO) Child Growth Standards) among children under 5 years of age 2.2.2 Prevalence of malnutrition (weight for height >+2 or <-2 standard deviation from the median of the WHO Child Growth Standards) among children under 5 years of age, by type (wasting and overweight)	Climate change will make it more difficult to achieve this goal. It has been estimated that warming of $1.5^{o}C$ is associated with an increase in the global undernourished population to 530–550 million; and to 540–590 million at $2^{o}C$ (Hasegawa et al., 2016).
3. Ensure healthy lives and promote well-being for all at all ages 3.2 By 2030, end preventable deaths of newborns and children under 5 years of age, with all countries aiming to reduce neonatal mortality to at least as low as 12 per 1,000 live births and under-5 mortality to at least as low as 25 per 1,000 live births 3.3 By 2030, end the epidemics of AIDS, tuberculosis, malaria and neglected tropical diseases and combat hepatitis, water-borne diseases and other communicable diseases	3.2.1 Under-five mortality rate 3.3.3 Malaria incidence per 1,000 population 3.3.5 Number of people requiring interventions against neglected tropical diseases [e.g. dengue, schistosomiasis]	Climate change will make it more difficult to achieve this goal. Preventable diseases including major causes of child mortality are projected to worsen; the distribution of malaria, dengue and neglected tropical diseases, water-borne diseases and other communicable diseases is projected to change, with net increases in climate-related risks in most cases. Mental health is affected by food and water insecurity, loss of livelihoods and the effects of climate related disasters. It may be possible to maintain and improve UHC with substantial investments in climate-resilient health care.

Table 1, continued.

Goal/Targets	Indicator	Potential impact of climate change on health
3.4 By 2030, reduce by one third premature mortality from non-communicable diseases through prevention and treatment and promote mental health and well-being 3.8 Achieve universal health coverage, including financial risk protection, access to quality essential health-care services and access to safe, effective, quality and affordable essential medicines and vaccines for all 3.9 By 2030, substantially reduce the number of deaths and illnesses from hazardous chemicals and air, water and soil pollution and contamination	3.4.2 Suicide mortality rate 3.8.1 Coverage of essential health services (defined as the average coverage of essential services based on tracer interventions that include reproductive, maternal, newborn and child health, infectious diseases, non-communicable diseases and service capacity and access, among the general and the most disadvantaged population) 3.9.1 Mortality rate attributed to household and ambient air pollution 3.9.2 Mortality rate attributed to unsafe water, unsafe sanitation and lack of hygiene (exposure to unsafe Water, Sanitation and Hygiene for All (WASH) services)	Climate change is projected to worsen near-surface ozone pollution, but will have mixed effects on other major pollutants (including particulate matter) depending on the interplay between altered emissions, wind speeds and atmospheric chemistry.
6. Ensure availability and sustainable management of water and sanitation for all 6.1 By 2030, achieve universal and equitable access to safe and affordable drinking water for all 6.2 By 2030, achieve access to adequate and equitable sanitation and hygiene for all and end open defecation, paying special attention to the needs of women and girls and those in vulnerable situations	6.1.1 Proportion of population using safely managed drinking water services 6.2.2 Proportion of population using safely managed sanitation services, including a hand-washing facility with soap and water	Increasing temperatures and unpredictable rainfall patterns will tend to increase mortality from bacterial enteric diseases while worsening water availability and quality. Sanitation systems relying on water supplies will also be less resilient as a result of increasing frequency and/or severity of climate related extreme events and disasters. It has been estimated that warming of 1.5°C would result in 496 million (range 103–1159) people exposed and vulnerable to water stress (Roy et al., 2018).
7. Ensure access to affordable, reliable, sustainable and modern energy for all 7.1 By 2030, ensure universal access to affordable, reliable and modern energy services	7.1.2 Proportion of population with primary reliance on clean fuels and technology	Increasing energy costs due to carbon charges will tend to worsen energy security.
8. Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all 8.8 Protect labour rights and promote safe and secure working environments for all workers, including migrant workers, in particular women migrants, and those in precarious employment	8.8.1 Frequency rates of fatal and non-fatal occupational injuries, by sex and migrant status	Heat exposure will reduce ability to perform physical work, especially outdoors. Mortality and morbidity from occupational heat exposure will increase, unless adaptation effective measures are implemented. This will be difficult, especially for outdoor workers.

Table 1, continued.

Goal/Targets	Indicator	Potential impact of climate change on health
11. Make cities and human settlements inclusive, safe, resilient and sustainable 11.5 By 2030, significantly reduce the number of deaths and the number of people affected and substantially decrease the direct economic losses relative to global gross domestic product caused by disasters, including water-related disasters, with a focus on protecting the poor and people in vulnerable situations 11.6 By 2030, reduce the adverse per capita environmental impact of cities, including by paying special attention to air quality and municipal and other waste management	11.5.1 Number of deaths, missing persons and persons affected by disaster per 100,000 people 11.6.2 Annual mean levels of fine particulate matter (e.g. PM2.5 and PM10) in cities (population weighted)	As above Climate change will have mixed effects, as above
13 Take urgent action to combat climate change and its impacts 13.1 Strengthen resilience and adaptive capacity to climate-related hazards and natural disasters in all countries	13.1.1 Number of deaths, missing persons and persons affected by disaster per 100,000 people	Resilience and adaptive capacity are likely to be weakened, especially in poor countries, in the face of increasing frequency and/or severity of climate related disasters (heatwaves, fires, droughts, storms, sea level rise, floods)
16. Promote peaceful and inclusive societies for sustainable development, provide access to justice for all and build effective, accountable and inclusive institutions at all levels 16.1 Significantly reduce all forms of violence and related death rates everywhere	16.1.1 Number of victims of intentional homicide per 100,000 population, by sex and age 16.1.2 Conflict-related deaths per 100,000 population, by sex, age and cause	Soil degradation, freshwater scarcity, population pressures, and other forces that are related to climate are all potential causes of conflict. The relationships are not straightforward, however, as many factors influence conflict and violence, and the evidence is contested. Also, it is noted that populations affected by violence are particularly vulnerable to the impacts of climate change on health and social wellbeing. (Smith et al., 2014)

First set of challenges: Untangling the relations between climate change, sustainable development, poverty and health.

This section considers the implications of the interactions between, firstly, climate change and sustainable development, and secondly, poverty and health (Figure 2), for health impact assessments.

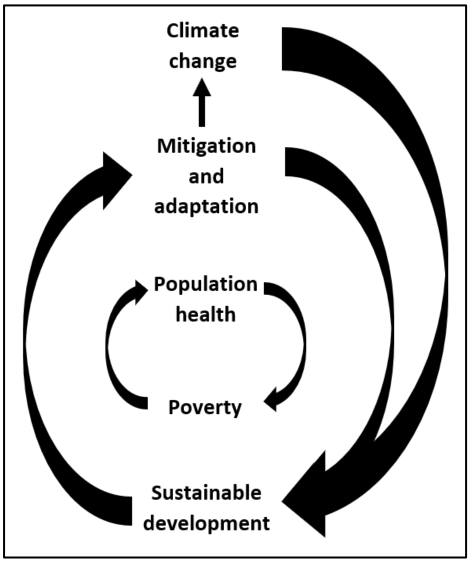


Figure 2 The interactions between climate change and sustainable development, and occurring within this, the interactions between population health and poverty.

The transformational global programmes to limit global warming to 1.5^{o} (United Nations, 2015a) and to meet the SDGs (United Nations, 2015b) potentially interact in both synergistic and contradictory ways (Roy et al., 2018). Their national implementation, however, is generally the responsibility of different ministries and this further complicates the already difficult task of maximising synergies (Dzebo et al., 2018). From a health perspective, these interactions make assessing the health impacts – particularly on the most vulnerable groups - of these combined programmes challenging.

Roy et al. (2018) discuss the general mechanisms of interaction between the 1.5^{o} targets and meeting the SDGs. Firstly, the impacts of climate change may impair achievement of the SDGs, for example via impacts of food security. Secondly, policies to mitigate and adapt to climate change may act synergistically with the SDGs (e.g. sustainable forest management may reduce emission and provide food and clean water), or may impair them (e.g. if land is dedicated to bioenergy production without careful management, food and water security may decline and conflict may arise). Thirdly, progress towards the SDGs could potentially mean populations lifted out poverty may consume more fossil fuel-derived energy, thus increasing carbon emissions and worsening climate change. Development does not, however, necessarily contradict the possibility of environmentally low impact living (Haines et al., 2012), and in fact, many climate change mitigation actions also bring health co-benefits (Haines, 2017). Finally, progress on the SDGs would be expected to reduce population vulnerability to the impacts of climate change.

Given these complexities, it is necessary to pursue development pathways that ensure both equitable and low carbon futures, via, for example, Climate-Resilient Development Pathways (CRDPs) (Roy et al., 2018). Improved population health and health protection should be key aspects of CRDPs, with interactions between health, sustainable development and climate change being formally assessed.

To date, assessments of the potential future health impacts of climate change on health have tended to focus in more detail on aspects of climate change than socioeconomic development. There are two reasons for this. Firstly, such health assessments are often part of a larger climate change-focussed project, or they explicitly set out to examine different climate futures. Secondly, the available socioeconomic projection data tend to be limited in scope (e.g. to GDP and population). This is not to suggest that socioeconomic factors are not considered in health assessments; ensuring – for example - the compatibility between climate and socioeconomic scenarios is generally a key consideration. Rather, it suggests that the means of representing socioeconomic futures are generally quite limited [We discuss this in more detail in the next section].

> ***Challenge 1.1:*** *The health impact community, in collaboration with other disciplines, should consider developing health impact assessments that specifically aim to consider the interactions between progress on the Paris Agreement (as well as more pessimistic climate futures) and the 2030 Agenda, in order to assess the health implications of future pathways, with a particular focus on groups who may most benefit or be most harmed.*

A second consideration is the mutually conditioning relation between population health and poverty. The nature of this depends on how poverty[5] is defined. The global multidimensional poverty index (MPI), for instance, includes, along with income, indicators of health as well as causes of ill health such as education, living standards and quality of work (De La O Campos et al., 2018). From this perspective, then, ill health and risk factors for ill health *are* poverty. From a health impact perspective, however, this does not obviate the need to understand *how* these factors are connected.

For instance, Lloyd et al. (2018) developed a model to assess how climate change impacts on food prices and the incomes of the poorest parts of populations may influence future child stunting (height-for-age) in rural and urban areas. The health model was driven by an upstream poverty model (Hallegatte and Rozenberg, 2017), which projected income patterns in 2030 under various climate and socioeconomic scenarios. In the poverty model, estimates of how climate change impacted on a range factors were used, in turn, to estimate impacts on household incomes. Amongst these factors were health outcomes, including malaria, diarrhoeal disease, labour productivity loss, and stunting.

That is, the poverty model considered stunting to be a cause of low incomes, while - conversely - the health model aimed to view low income as a cause of stunting. This could be untangled as, on one hand, the health model aimed to look at stunting risk in children in low income households; on the other hand, the poverty model, considered income losses in adults who were irreversibly stunted as children. Together, in theory[6], this captures the transmission of risk of having a low income from one generation to the next via stunting. This illustrates how a mechanistic understanding can help untangle reciprocal relations; it also raises an additional point.

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[5] As well as health.

[6] In theory because the health and poverty models were not formally linked, and the health model considered just two time points.

The poverty model explicitly represents various routes from climate change to poverty. In contrast, the health model is based on a statistical correlation between low income and stunting. This has an advantage in that it (arguably) captures the full effects of income on stunting regardless of the specific causal pathway[7], and thus may provide reasonable predictions. However, in future work consideration should be given to representing specific mechanistic pathways from poverty to health, as this may better guide health protection policy.

Research on causal pathways in obesity provides an analogy (Chiolero, 2018). Obesity is a marker of risk for disease, but this risk operates through multiple causal mechanisms (e.g. diet, physical activity); further, the impact of an obesity reduction programmes on disease *depends on how* weight gain is prevented. Likewise, poverty is a marker for health risk, but the health benefits of actions to reduce poverty *will depend on how* poverty is reduced. In turn, developing understandings of this is likely to depend on underlying understandings of the causes of poverty; for example, residual or relational theories (Bernstein, 1992)[8].

> ***Challenge 1.2***: *As well as further developing assessments that predict the impacts of poverty on health, additional assessments based on specific causal mechanisms by which poverty affects health may help show which types of actions to reduce poverty are likely to have the greatest health benefits, thus also reducing causal feedback from ill health to poverty.*

We now move to the representation of rural areas in climate-health assessments.

[7] Here, we followed the general logic outlined by Biggs et al. (2010). Although other factors, such as education and access to water and sanitation, affect stunting, they are also likely to be strongly influenced by incomes. This influence means that: a) if such factors were added to a regression model, they would absorb some of the effects of income on stunting; and b) such factors are likely to be highly collinear with income and may cause model fitting problems. Thus, by including just income and price, we attempt to capture their full effects regardless of the specific causal pathway from the predictors to the outcomes.

[8] Broadly, residual theories see poverty as due to being 'left out' while relational theories view both wealth and poverty as being generated by the same set of processes.

Second set of challenges: Representing rural areas in scenario-based climate-health impact assessments

Rural areas have distinct qualities in terms of both people and place, bringing particular patterns of ill health and climate-associated risks. However, representing this in scenario-based climate-health impact assessments poses significant challenges. In fact, in this body of work[9] – at least to our knowledge – it is uncommon to include a rural-specific focus. This, in turn, partly arises due to a paucity of empirical studies focussed on specifically on health impacts in rural areas (e.g. Dasgupta, 2014, p631). Indicatively, in 2012, a review of >19,000 abstracts from "climate change" focussed papers (using automated methods) in the health and social sciences literature found that "rural" appeared in only 3% of abstracts (Bell, 2013)[10]. Further suggesting a general lack of literature, the health chapter of the IPCCs Fifth Assessment Report (Smith et al., 2014) discusses rural-specific impacts based on just five papers[11],[12].

Despite this apparent dearth, the results of many scenario-based impact assessments are often shown at high spatial resolution; for example, in 100 km^2 grid cells. What enables this is the availability of high-resolution climate data. In many, if not most, cases, however, the associated socioeconomic data are very limited. That is, the question, "what's going on in a grid cell?", is generally difficult to answer in terms socioeconomic processes. In other words, the spatial precision enabled by climate models is coupled with imprecision of socioeconomic data; the upshot is that estimates provided by health impact assessment may at times give a false sense of spatial precision. Otto et al. (2015) highlight this climate-socioeconomic scalar mismatch and call for efforts to collect more sub-national socioeconomic data using novel methods. This would allow better representation of rural areas.

In scenario-based assessments, the general approach currently adopted is to represent socioeconomic futures using the Shared Socioeconomic Pathways (SSPs) (O'Neill et al., 2017). There are five pathways, each representing plausible futures which differ by challenges faced in climate change mitigation and adaptation. The scenarios are described by detailed qualitative narratives, covering areas including population growth, economic growth, technological trends, education and health care investment, and inequalities (Riahi et al., 2017). Accompanying health narratives have also been developed (Ebi, 2013). However, quantified data for the SSPs have until very recently been limited to population, Gross Domestic Product (GDP), education, and percent of a population that are urban, initially projected at the national-level but subsequently gridded to a spatial resolution of 1 degree by 1 degree (or higher) (IIASA, 2018, Jones and O'Neill, 2016, Wittgenstein Centre for Demography and Global Human Capital, 2017). Given this paucity of data, it has been typical to represent development in health impact assessments using GDP/capita, with no qualitative distinction between rural and urban areas (e.g. Hales et al., 2014).

For instance, in Lloyd et al. (2011) we aimed to project future child stunting in South Asia and sub-Saharan Africa in 2050 under moderate to high climate change. A wide range of factors are associated

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[9] We stress that we are specifically referring to scenario-based climate-health impact assessments here.

[10] Bell included any climate change focussed paper, not just scenario-based health impact assessments. The automated method had limitations (as acknowledged by the author), but the results are suggestive of general patterns in the literature.

[11] These cover suicide risk, risk to subsistence farmers, rural vulnerability, and flood mortality. Note that we are not suggesting that only five recently published papers covered climate change-attributable health impacts rural areas. We also note that the rural chapter (Dasgupta, 2014) of this IPCC report refers readers to the health chapter for an overview of health impacts.

[12] As mentioned above, there are limited references to health impacts in rural areas in the Lancet Countdown (Watts et al., 2018) or the health section of the IPCC 1.5^{o} report (Hoegh-Guldberg et al., 2018).

with stunting (many of which are included in the SDGs; e.g. female education, water and sanitation access, infectious diseases) (UNICEF, 1990), and food availability or access may often not be the most important cause (Smith and Haddad, 2015). However, data limitations restricted development to being represented as national-level GDP/capita[13].

This severely limited the possibility of representing the combined impacts and interactions of climate change and development. More generally, this situation has persisted and applies to assessments across a range of health outcomes. This is a key issue, as adopting GDP/capita as the sole representative of development may potentially lead to model results that appear to suggest GDP growth is the key to improving and protecting health of poor populations[14]. However, the relation between GDP/capita and health is socially-mediated and differs by country (e.g. Bernstein, 1992, pp. 13-16). In fact, an explicit goal of development may be to, in effect, change the relationship between GDP and health via – for instance – redistributive social protection measures (De La O Campos et al., 2018). Relatedly, Biggs et al. (2010) found that in Latin American countries, if GDP/capita and inequality both grew, there were no benefits to life expectancy and only small benefits on infant mortality (In other words, the GDP-health relationship changed as inequalities rose). If the benefits (or harms) of development processes are to be assessed, it is essential for health assessments to use more subtle representations.

In a recent study using the stunting model described above (Lloyd et al., 2014) (Figure 3), we found that socioeconomic conditions (blue bars) have a much greater influence on the magnitude of estimated child stunting than climate change (with climate-change attributable stunting shown as orange bars). Yet socioeconomic conditions are represented crudely as GDP/capita. While these results are partly an artefact of the model and modelling strategy, it is clearly evident that priority should be given to developing means of better representing aspects of development, and of gaining an improved understanding of the combined effects of development and climate change.

[13] In this paper we used an earlier round of socioeconomic scenarios, however data limitations were similar to those of the SSPs. Note that we attempted to adjust GDP for inequality (using Gini coefficients) but as no projections were available we held these constant at current levels.

[14] Of course, it is unlikely the researcher will fully adopt this interpretation; however, once research produces numbers it is open to interpretation by various groups.

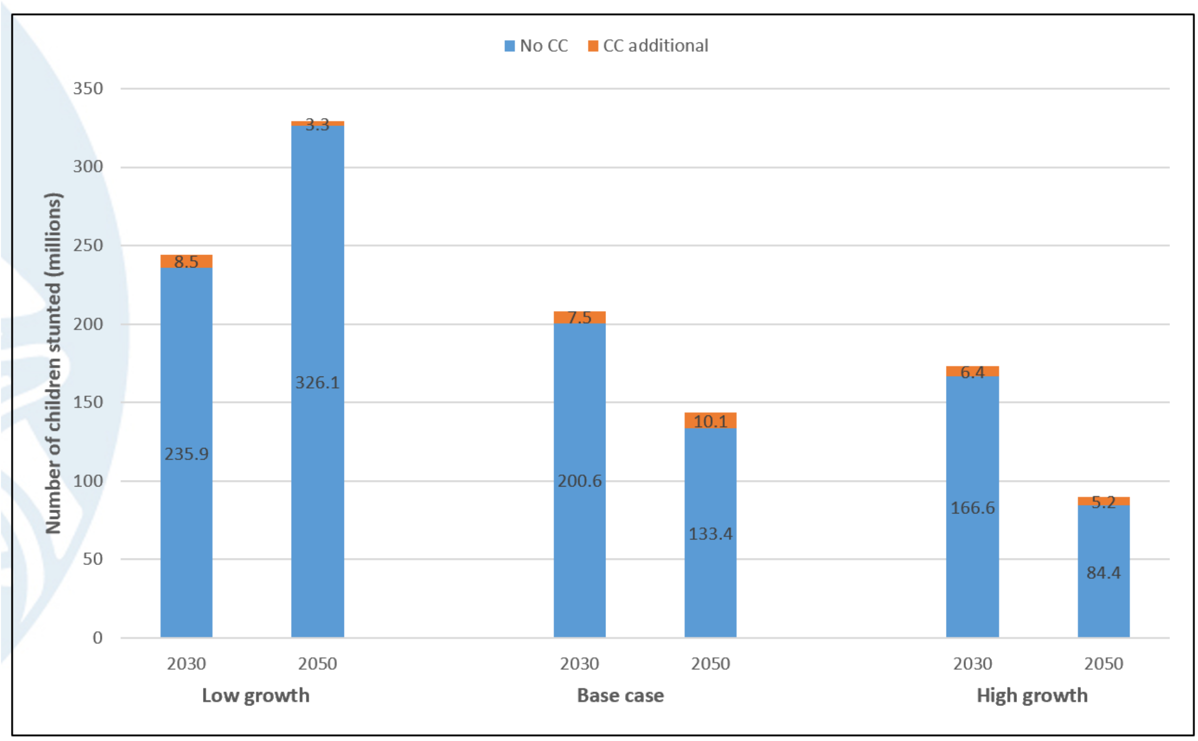

Figure 3 Estimates of the number of children stunted in futures with and without climate change (orange [as additional with climate change] and blue bars, respectively) in 2030 and 2050, under A1b emissions and three socioeconomic scenarios (low growth, base case, high growth)
Source: Based on (Lloyd et al., 2014)

Important steps towards enabling this have recently been made with the release of SSP-specific scenario data for urban-rural equity and poverty, including Gini coefficients and income distributions, and spatially-explicit data will soon be available (Rao et al., 2019; personal communication with Keywan Riahi). Microsimulation has also been used to generate future trajectories of poverty in agricultural and non-agricultural households (Hallegatte et al., 2016, Hallegatte and Rozenberg, 2017). Additionally, SSP-specific cause of death data are being developed at the University of Washington. These new data will better enable researchers to assess future health impacts in rural areas and to explicitly account for poverty and inequality.

> ***Challenge 2.1:*** *Health researchers and modellers should attempt to better represent development in assessments (including its uneven distribution), by rapidly adopting newly available SSP scenario data.*

Of course, rural areas have qualities that will influence the impacts of climate change on health beyond income poverty. For instance, risks may be exacerbated by shocks to crop productivity, by population density and proximity, and by a lack of infrastructure (e.g. water and sanitation) and services (e.g. health services). While these features are likely to be heterogenous across rural areas, it may be possible to develop general representations of key types of area – based on, for example, “archetype analysis” (e.g. Sietz et al., 2017) – and build these into health impact assessments by developing trajectories based on the SSP narratives. Such an approach may balance the need for parsimony in models with real-world heterogeneity.

Challenge 2.2: *Health researchers and modellers should explore means of representing the qualities of rural areas that are likely to shape the climate-health relation, perhaps by developing typologies in order to balance real-world heterogeneity and model parsimony*

A final issue when representing rural areas is the size of populations and their future trajectories. Urbanization trends have been projected based on the SSP-narratives (Jiang and O'Neill, 2017) and are shown in Figure 4, Panel A. The x-axis is year, running from 1950 to 2100, with the y-axis showing % urban; the plots are based on historical data and projections under the five SSPs. Three of the SSPs (representing Sustainability (SSP1), Fossil-Fuelled development (SSP5), and Inequality (SSP4)) reach 92% urban by 2100, with Middle-of-the-Road (SSP2) reaching 79%, and Regional Rivalry (SSP3) reaching 60%. That is, the most optimistic scenarios have relatively small rural populations by the end of the century, and a substantially sized population is only seen in a pessimistic scenario. An example of the implications of this is shown in Figure 4, Panel B. The x-axis shows year, running from 2010 to 2100, and the y-axis shows lost labour time in outdoor labour (e.g. agriculture) due to heat stress. The blue line shows impacts if % urban is held constant at 2010 levels; the red line shows the impacts if urbanization under SSP2 (i.e. 79% by 2100) is accounted for. In the latter, the drop is presumably due to a large reduction in the proportion of the population with agriculturally-based livelihoods. That is, if it is assumed the future will be de-ruralised, the apparent threat of climate change – at least for some health outcomes - drops substantially.

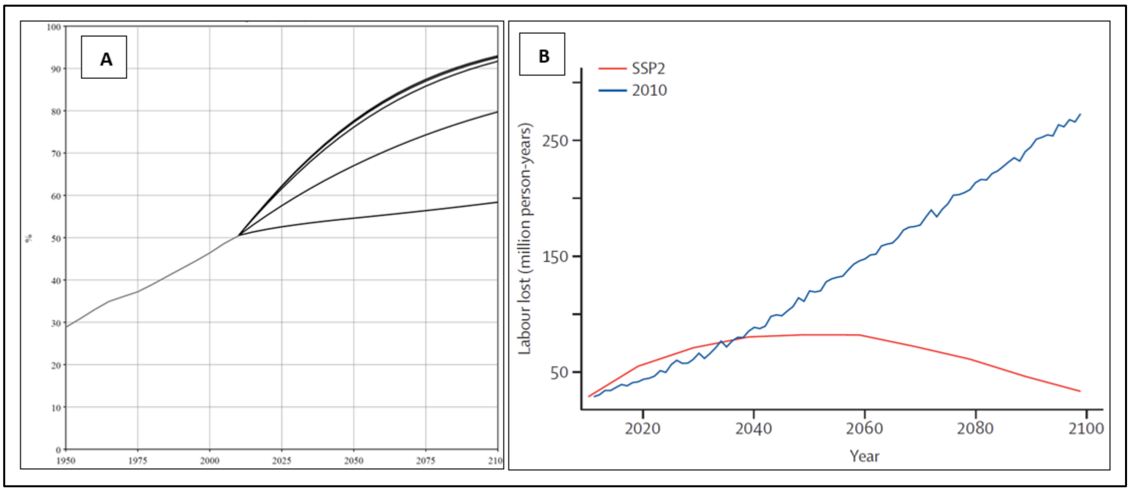

Figure 4, Panel A: Historical and projected % urban (y-axis) for the five SSPs out to 2100, reaching 92% for SSPs 1, 4 & 5, 79% for SSP2, and 60% for SSP3. Panel B: Outdoor labour lost out to 2100 under high climate change, holding % urban constant at 2010 levels (blue) and allowing for projected urbanisation under SSP2 (red).
Sources: Panel A: IIASA SSP database v0.9.3; Panel B: Watts et al. (2015)

These urbanization projections are based on historical data and standard projection methods, and are plausible. However, a gap that could potentially be explored is optimistic futures in which rural populations remain relatively larger. For instance, this may be an agroecology-base future (Altieri et al., 2015), in which agricultural labour conditions are improved and seen more positively (Timmermann and Félix, 2015), potentially creating more vibrant and sustainable rural communities, addressing both food security and food sovereignty (Patel, 2009). Under the current scenarios, the potential and implications of such futures cannot be formally assessed.

Challenge 2.3 *The climate change impacts community could consider developing socioeconomic scenarios that assume structural conditions support the development of vibrant* *rural communities, where agriculture remains a significant source of employment, perhaps via agroecology.*

In sum, the general lack of health assessments that specifically focus on rural areas is associated with both a lack of projection data with which to represent rural areas, and – arguably – the general assumption[15] that there will be a (relative) lack of rural populations in 'optimistic' futures.

In the next section we consider additional challenges faced in health assessments.

[15] Not to suggest that there is no empirical grounding for this assumption.

Third set of challenges: Assessing health impacts in scenario-based assessments

In this section, we predominantly use our previous work on undernutrition assessments to draw out some general challenges. Following this we briefly discuss issues around climate-related disasters and vulnerability.

In the majority of global-level assessments of climate change and undernutrition (e.g. Hasegawa et al., 2015, Nelson et al., 2010, Ishida et al., 2014, Lloyd et al., 2011), climate change affects nutrition via a single route – its impacts on crop productivity. However, climate change may impact on future nutrition via multiple routes, including through its impacts on socioeconomic conditions. Lloyd et al. (2018) took an initial step towards addressing this gap, developing a model to assess how climate change impacts on the incomes of the poorest parts of populations in urban and rural areas may in turn impact on future undernutrition. This posed a number of challenges.

The first was in relation to the availability of poverty data for rural and urban areas. Historical poverty data[16] that were urban-rural split were, unexpectedly, too limited to develop an empirically-based undernutrition model[17]. Consequently, we were unable to directly include poverty in our assessment. Instead, data on average incomes of the bottom 20% of a national population were combined with estimates of rural and urban income or consumption to develop an indicator of rural and urban incomes.

More generally, the situation in which - despite the availability of apparently precise global-level estimates of a health or development statistic - there is a lack of globally-comparable historical data at the national- or local-level (especially for lower income countries and poorer populations) appears to be reasonably common, although the situation is improving (Jerven, 2018). Additionally, the quality of available data is often questionable, and their uncritical use may lead to misleading inferences. For instance, Jerven (2013) concluded that many development statistics for Africa have very large errors and margins of uncertainty despite potentially being used to make decision about resource allocation; Mathers et al. (2005) pointed out that in 2003, about 40% of WHO member states (including 42 countries in Africa) had mortality data (one of the most basic health statistics) of inadequate quality to support policy decisions; Jerven (2018) noted that population counts are frequently distorted for political reasons. The upshot is that researches should routinely critically assess the quality of available health and development data, particularly in terms of the potential influence this may have health assessments.

> ***Challenge 3.1*** *When developing empirically-based health assessment models, researchers should critically assess the quality of apparently robust historical data to avoid drawing misleading conclusion about health impacts and policy priorities; this may be particularly pertinent to many rural areas where data may be based on extrapolations.*

Secondly, the above assessment set out primarily to *quantify* future impacts on stunting. Here, the findings suggested that futures in which incomes of the poorest remain low and in which climate

[16] Specifically, for poverty associated with household income.

[17] Significantly more national-level data were available, but an explicit aim of our model was to represent rural and urban areas.

change is allowed to worsen will have significantly more child stunting in the near-term than futures in which incomes of the poorest rise and climate change is mitigated. Further, in the former, not only would more stunted children be expected: the degree of stunting would tend to be worse, and a greater proportion of the burden would fall on rural areas.

However, arguably the most interesting findings related to the *qualitative patterns* in the results. These suggested that when incomes of the poorest are low and prices (relative to income) rise fairly abruptly, (as expected) stunting tends to increase. But the results also showed that when incomes of the poorest are higher, gradual rises in relative price may reduce stunting. Drawing on theory and previous empirical work (Hertel, 2016, Mazoyer and Roudart, 2006), this suggests the underlying mechanism is that sustained higher prices raise both farm incomes and rural wages, thus reducing the risk of both undernutrition and the risk that climate change poses to nutritional status.

These findings highlight the potential benefits of consciously adopting an 'open' approach to science, where 'researchers take seriously unforeseen turns of data, which may cause them to jump tracks and think outside the box' (Sennett, 2018)[18],[19]. More generally, this alludes to the potential usefulness of combining insights of models that 'seek to predict' (the route most commonly taken in climate-health assessments) with models that 'seek to explain' (e.g. Hedström, 2005)[20]. In this approach, predictions would identify possible priorities and explanations would guiding actions. An advantage of such an approach is that some forms of explanatory models may be less data demanding, potentially allowing assessments of risks in rural areas where data may be lacking.

> ***Challenge 3.2*** *Given the inherent complexity of the relations between health, climate change, development, health researchers should consider (i) consciously adopting an 'open' approach to science (by, for example, exploring unforeseen turns in results), and (ii) combining insights from quantitative predictive models with insights from qualitative explanatory models, the latter being potentially useful in rural areas with limited data availability*

The third challenge is about future time horizons of projections. In the above assessment, as the health impact model was driven by an upstream poverty model, we were only able to make projections out to 2030. While this reaches the target year for the SDGs, the assessment of the potential health impacts of climate change beyond 2030 remains essential. The locked-in differences between futures with lower or higher carbon emissions do not begin to vary widely until around 2050s and differ substantially by 2100 (Figure 5) (Collins et al., 2013)[21]. That is, in order to bring to light the full health consequences of unmitigated climate change, it is necessary to look further into the future.

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[18] Sennett (2018) also discusses such an open process in adaptive clinical trials of new drugs referred to by a Harvard physician, in which there may be more interest 'in making sense of things that are surprising or intriguing than in confirming what might have been predictable in advance'. Given the complexities of the relations between climate, development, and health, this principle arguably has a key role to play in developing and interpreting assessments of climate-health analyses and models

[19] We by no means intend to suggests researchers do not currently investigate unexpected patterns in their results. Rather we mean to suggest that their may be benefits from more consciously bringing this to the foreground.

[20] To our knowledge, such an approach is rarely used in climate-health assessments; however it has been adopted in other areas in population health, such as obesity research (e.g. Hennessy et al., 2016).

[21] This by no means suggests that climate change will not have substantial impacts in 2030; only that between-emissions scenario differences are yet to be fully expressed.

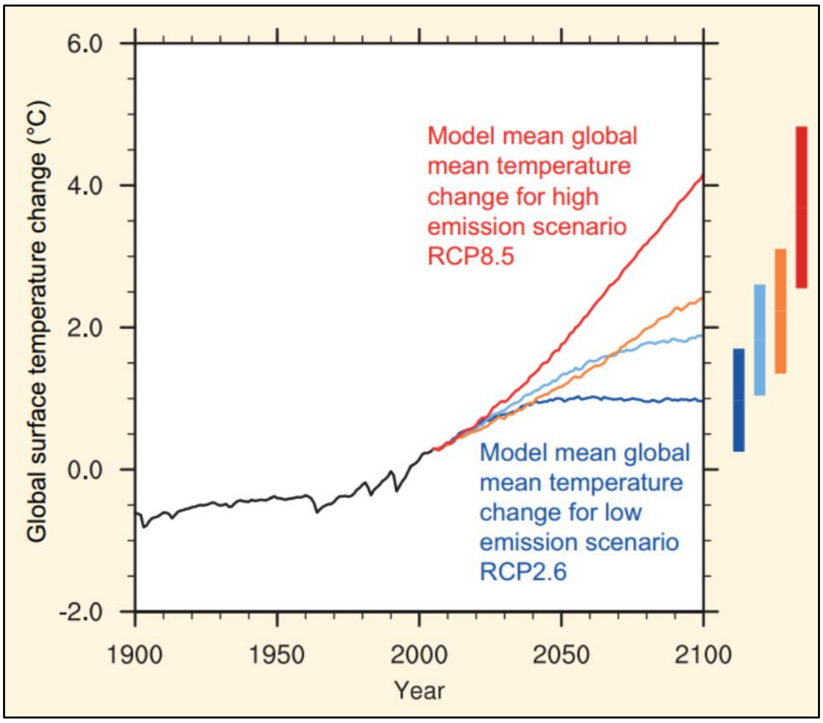

Figure 5 Average trajectories of future warming (y-axis) under the emissions scenarios used in IPCC AR5 (shown by the coloured plots) out to the year 2100 (y-axis); see original caption[22] for further details.
Source: Collins et al. (2013)

Maintaining the progress made through the SDGs by 2030, as well as ongoing improvement in people's health, is likely to be compromised according the magnitude of climate change beyond 2030. Crucially, it is possible – perhaps likely - that the groups in greatest jeopardy would be precisely those in rural areas who had been recently lifted out of poverty. Developing detailed socioeconomic scenarios that extend beyond 2030 is challenging; but, the new SSP-specific poverty and inequality data mentioned above (Rao et al., 2019) extend to 2050 and are thus are an important first step.

> ***Challenge 3.3:*** *The differences between futures with lower and higher carbon emissions do not begin to vary widely until around the 2050s; in order to assess threats to progress made under the SDGs, and to help ensure ongoing progress, it is necessary to develop detailed socioeconomic scenarios that extend beyond 2030 and represent the most vulnerable groups, and to utilise these scenarios in health assessments.*

A forth challenge is about interdisciplinary working. The typically modelled pathway runs along a chain of models from climate to crops to food trade to national food availability to undernutrition (e.g.

[22] Original caption: "FAQ 12.1, Figure 1: Global mean temperature change averaged across all Coupled Model Intercomparison Project Phase 5 (CMIP5) models (relative to 1986–2005) for the four Representative Concentration Pathway (RCP) scenarios: RCP2.6 (dark blue), RCP4.5 (light blue), RCP6.0 (orange) and RCP8.5 (red); 32, 42, 25 and 39 models were used respectively for these 4 scenarios. Likely ranges for global temperature change by the end of the 21st century are indicated by vertical bars. Note that these ranges apply to the difference between two 20-year means, 2081–2100 relative to 1986–2005, which accounts for the bars being centred at a smaller value than the end point of the annual trajectories. For the highest (RCP8.5) and lowest (RCP2.6) scenario, illustrative maps of surface temperature change at the end of the 21st century (2081–2100 relative to 1986–2005) are shown for two CMIP5 models. These models are chosen to show a rather broad range of response, but this particular set is not representative of any measure of model response uncertainty."

Hasegawa et al., 2015, Ishida et al., 2014, Lloyd et al., 2011, Nelson et al., 2010). Health models sit at the end of this chain and this means they necessarily inherit the assumptions of upstream models. Of course, all health assessments require assumptions, and this is not a problem in itself. But, the assumptions restrict the range of processes it is possible to represent in health models. For instance, the chain of models splits production (which sits at the start of the chain) from consumption (which sits at the end). Yet, smallholder producer-consumers are estimated to comprise the majority of people living in poverty and around half the world's undernourished (IFAD, 2011). This group, as well as their potential futures, should arguably be of particular interest in health assessments that include coverage of rural areas, yet they cannot be represented within the existing framework. Local level assessments could be used to overcome this, but global-level processes also influence local conditions (Mazoyer and Roudart, 2006)[23].

Assessments such as Lloyd et al. (2011) are developed in a multidisciplinary[24] setting: here, groups from different disciplines tackle different parts of a problem, and then these parts are linked together. This is a productive approach, but aspects of a problem that are a side issue for one discipline may be of central concern to another. Given this, it may be fruitful to develop assessment models jointly from the start so as to capture elements aspects of a problem that have previously been neglected. For example, in addition to the separation of consumption and production outlined above, the assumption of perfect markets in trade models may obscure market distortions that shape food prices and place many at risk of undernutrition.

> ***Challenge 3.4:*** *New interdisciplinary approaches to health impact assessments could be developed jointly with specialists from other disciplines to allow the investigation of processes shaping health that may be systematically excluded from exiting multidisciplinary models, particularly those processes that may unevenly impact on poorer communities.*

A final challenge arising for climate-undernutrition assessments is about leveraging the global. The majority of assessments we have been involved in have been multi-regional or global; more generally, this is often the case for a range of health outcomes and for many ongoing projects. Local-level assessments are better able to capture the rich details of everyday life and its setting, but global-level assessments arguably shouldn't be seen as "more blurry" representation of the local. Rather, they – at least potentially – could capture a range of processes operating at higher-levels but affecting rural areas. Bernstein (1992), for instance, suggests that questions about land, labour, and livelihood in rural areas may be explored at multiple levels in order to give a more complete picture. Possibly relevant processes for rural poverty and health include those associated with global class structures (Cohen and Perrier, 2013), privileges bestowed on national leaders via the international order (Pogge, 2010), relational-poverty arising via global competitive advantage (Kaplinsky, 2005), and tendencies towards excessively low food prices (Mazoyer and Roudart, 2006). We suggest that, perhaps, explicitly including such processes in global-level health assessment may offer new insights.

> ***Challenge 3.5:*** *Global-level assessments potentially offer different insights than those conducted at local-level; new insights into health in rural areas may be gained by attempting to incorporate relevant global processes – particularly those that influence patterns of poverty and inequality - into global-level assessments.*

[23] We return to this issue ahead.
[24] We use definitions from Daly and Farley (2011)

To conclude this section, we raise a challenge associated with climate-related disasters; before this we give some brief background. The Sendai Framework for Disaster Risk Reduction sets out seven targets - which are monitored via 38 indicators - for the period 2015 to 2030 (UNISDR, 2015). The targets are particularly relevant to health and poverty (e.g. aiming for reductions in mortality, number of people affected, economic losses, and damage to critical infrastructure) although no indicators explicitly focus on rural areas or poverty (albeit one indicator covers agricultural losses). Chan and Murray (2017) suggest that health should be at the heart of the Sendai Framework but raise a number of gaps. These include uncertainties in tracking the health-related indicators due to a lack of clear epidemiological definitions (e.g. in relation to temporality, attribution of health impacts, and baseline comparator data); and, the need to develop better understandings of the long-term impacts on mental health and wellbeing as well as vulnerabilities of population subgroups.

Climate change is expected to increase hazards - including floods, droughts, and temperature extremes - with poor people often (but not always) more exposed and usually loosing a greater proportion of their incomes and assets when affected (Hallegatte et al., 2016). The latter point raises two key issues. Firstly, impact assessments based on GDP losses will tend to miss the implications for poor populations as their incomes often comprise a small proportion of GDP (e.g. in Panama, the incomes of the poorest 20% of households represent just 3% of GDP); secondly, these disproportionate impacts on poor people will widen within-country income inequalities (Hallegatte et al., 2016, Hallegatte and Rozenberg, 2017), potentially deepening marginalization. Together, these would be expected to further increase vulnerability of low income populations.

This suggests that to better understand the health implications of climate-related disasters for poor rural populations, it is necessary for assessments to develop more detailed representations. Two core parts of this are the representation of hazards and of vulnerability. Arguably, representing physical hazards is less of a challenge, with existing models able to capture, for example, changing patterns of storm surge (e.g. Hinkel and Klein, 2009) and drought (Byers et al., 2018) under given climate scenarios. Vulnerability assessment poses more challenges, and Ribot (2014) raises two relevant issues. Firstly, with anthropocentric climate change, social causes of disasters are present in both the "hazardscape" and vulnerability, and this illustrates the link between causes of and responsibilities for both climate change and development. Unequal access to the opportunities whose emissions have driven climate change has partly generated both the poverty and marginalization which underlies vulnerability to hazards for some populations, and, the benefits that tend to make other populations less vulnerable. That is, at least partly, the same processes are driving both climate change and patterns of vulnerability. This further underlines the need to develop health assessments that better represent both climate change and development together (Challenge 1.1).

Secondly, Ribot (2014) contrasts two commonly used approaches to assessing risk (Figure 6). In the figure, the representation of climate-related factors in each approach is highlighted in blue. Panel A shows what may be called risk-hazard "impact analysis". Here, a causal relation is traced back from multiple outcomes (including those associated with health and poverty) to the hazard. This approach is common in impact assessments, with vulnerability typically represented as a dose-response function, which may be modified as socioeconomic conditions change (e.g. Lloyd et al., 2016). The upshot is that – in this approach - people tend to be cast as being vulnerable to *natural hazards*. In contrast, what may be characterised as livelihoods-based "vulnerability analysis" (Panel B) assesses how multiple (social, economic, political) causes result in vulnerability, with people seen as vulnerable to *undesired outcomes*. Climate-related hazards are seen as playing a role, but causation is located in society, with vulnerability (and/or risk) being an evolving condition of everyday life (e.g. Wisner et al., 2004).

While likely to be more difficult to implement in health assessments than risk-hazard approaches, the "vulnerability analysis" approach offers the advantages of more strongly avoiding the potential for "climate determinism" raised earlier (McMichael et al., 2017), and of enabling better representation of interactions between future climate and development pathways. In turn this should enable a better focus on groups that may be particularly vulnerable, particularly poor rural populations.

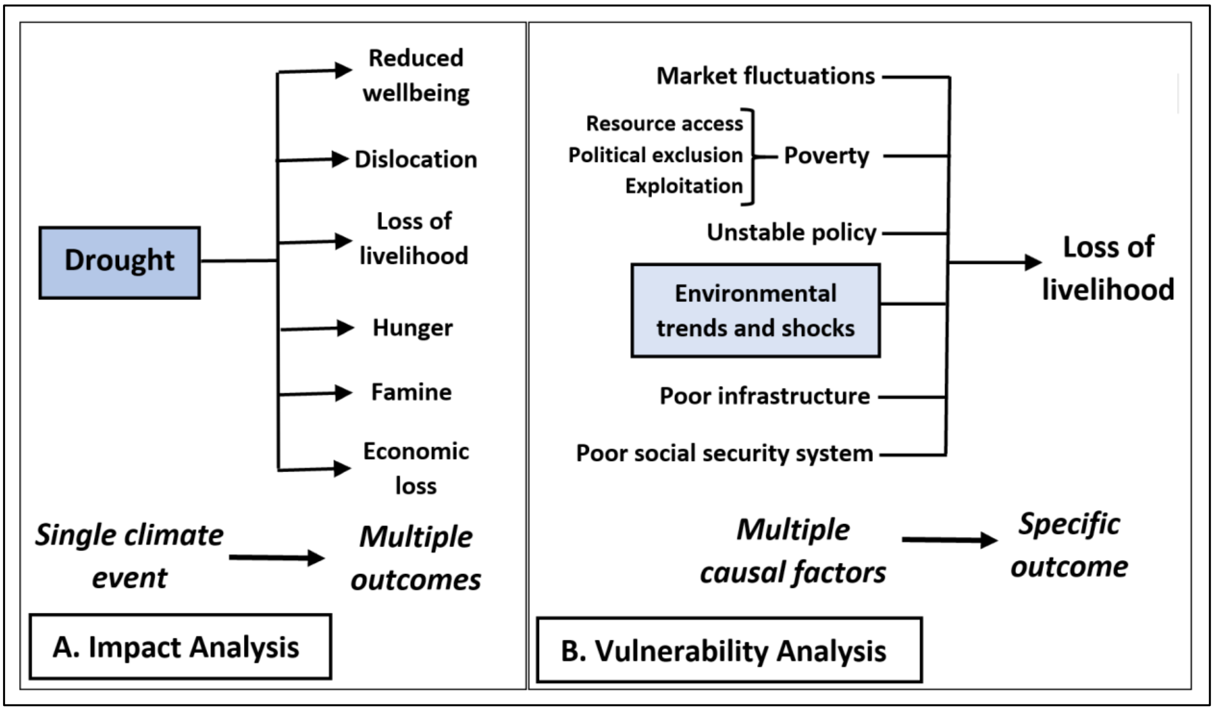

Figure 6 Two common approaches to assessing risk of climate-related disasters, with climate-related aspects highlighted in blue; Panel A - Risk-hazard "Impact analysis", Panel B – Livelihoods-based "Vulnerability analysis"
<u>**Source**</u>: based on figures 1 and 2 in Ribot (2014).

> ***Challenge 3.6:*** *In health assessments of climate-related disasters, as well using approaches that view people as being vulnerable to hazards, consideration should be given to adopting alternative approaches that more firmly locate the causation of vulnerability in society with hazards being one causes amongst many; such an approach may allow better assessment of the interactions between future climate and development pathways, particularly the implications for the most vulnerable populations.*

We now tie the identified challenges together to suggest how gaps in policy-relevant research may be filled.

Conclusions: Filling the gaps using policy-relevant health assessments

It has been argued elsewhere that because poverty carries the moral implication that something should be done about it, the study of it can only be justified if it influences attitudes and actions (Lister, 2004). Climate-health assessments may potentially achieve this, for the former, via driving advocacy for rural health and, for the latter, by guiding policy that aims to benefit the most vulnerable. The challenges identified above combine to identify two broad strategies that could help deliver this.

Firstly, health assessments that pay equal attention to both sustainable development and climate change should be developed. The importance of this is emphasised by the recognition that many of the (unevenly distributed) processes that drive climate change also drive (the uneven) distributions of incomes and vulnerability. To be clear, almost all existing climate-health assessments consider development, sometimes simply and sometimes more sophisticatedly. But, to our knowledge, at least in health assessments, the climate aspects have received far greater attention (at times due to a general lack of socioeconomic data). Given the synergistic and contradictory relations between the Paris Agreement and the 2030 Agenda, it is essential to assess the health implications of these interactions. Newly available socioeconomic scenario data better allows this (Rao et al., 2019), and efforts to expand these data further could be put in place (Otto et al., 2015). Such data should aim to extend beyond 2030 as this would allow an assessment of how worsening climate change further in the future may potentially undo progress made under the SDGs.

Given the centrality of rural poverty to achieving the SDGs, as the well as the need to ensure sustainable food systems for both rural vitality and global population health, future assessments should include an explicit focus on rural areas. To date, rural areas have rarely been a focal point of scenario-based health assessments. Further the ‘optimistic’ socioeconomic scenarios currently assume the relative size of rural populations will decline to perhaps as low as 8% (IIASA, 2018); new scenarios representing the possibility of futures with larger and thriving rural communities should perhaps be developed.

Both global- and local-level health assessments are required, as they each capture different aspects of real-world complexity. If possible, globally-level assessments should be leveraged so as to represent key global processes that may influence future patterns of poverty and inequality. Such assessments could be developed by deepening interdisciplinary collaboration, with groups developing assessment strategies and models collaboratively rather than connecting together independently developed models.

Finally, as suggested by Ebi et al. (2018), health assessments of potential futures should report both temperature change (as this provides a link to policy goals) and time (as this reflects the urgency of an issue) alongside health impacts.

The second strategy is about how modelling is approached. Alongside quantitative assessments that predict impacts (thus identifying potential priorities), assessments that seek to explain should also be developed. The latter may provide insights into causal mechanisms and identify the benefits and harms of various interventions. This approach also brings the advantage of requiring less data inputs, which may be particular useful in data poor rural areas. Relatedly, mechanistic representations of the routes from poverty to health should be utilised to assess how different type of actions to reduce poverty may affect health. Regardless of whether predictive or explanatory models are being used, the adoption of alternative theoretical frameworks to guide assessments should be considered: a key example here is the assessment of vulnerability, with different approaches locating causation more strongly in hazards or society.

When using data to build models it is essential to critically assess the data quality to avoid making misleading inferences. As Jerven (2018) points out, apparently robust global-level datasets may conceal a lack of data for many locations; this may particularly affect rural areas. Data gaps are often filled by extrapolation or modelling: in some cases, apparent statistical correlations between variables in a dataset may arise simply because the data were generated based on statistical correlations (e.g. Svedberg, 2000).

Overall, a key way of using health assessments to both advocate for and guide the achievement of both the Paris Agreement and the 2030 Agenda arguably lies in devising methods for examining genuinely transformative futures, with, for example, shifting balances of economic, political, and social power (e.g. Wright, 2010). The viability of such potential worlds could be examined in models, including health assessment models. Following this, the conditions for actually allowing the achievement of these potentials would need to be put in place. This, of course, is the greatest challenge.

References

ALTIERI, M. A., NICHOLLS, C. I., HENAO, A. & LANA, M. A. 2015. Agroecology and the design of climate change-resilient farming systems. *Agronomy for Sustainable Development,* 35**,** 869-890.

BELL, E. J. 2013. Climate change and health research: has it served rural communities? *Rural Remote Health,* 13**,** 2343.

BERNSTEIN, H. 1992. Poverty and the Poor. *In:* BERNSTEIN, H., CROW, B. & JOHNSON, H. (eds.) *Rural Livelihoods: Crises and Responses.*

BIGGS, B., KING, L., BASU, S. & STUCKLER, D. 2010. Is wealthier always healthier? The impact of national income level, inequality, and poverty on public health in Latin America. *Soc Sci Med,* 71**,** 266-73.

BYERS, E., GIDDEN, M., LECLÈRE, D., BALKOVIC, J., BUREK, P., EBI, K., GREVE, P., GREY, D., HAVLIK, P., HILLERS, A., JOHNSON, N., KAHIL, T., KREY, V., LANGAN, S., NAKICENOVIC, N., NOVAK, R., OBERSTEINER, M., PACHAURI, S., PALAZZO, A., PARKINSON, S., RAO, N. D., ROGELJ, J., SATOH, Y., WADA, Y., WILLAARTS, B. & RIAHI, K. 2018. Global exposure and vulnerability to multi-sector development and climate change hotspots. *Environmental Research Letters,* 13**,** 055012.

CHAN, E. Y. Y. & MURRAY, V. 2017. What are the health research needs for the Sendai Framework? *Lancet,* 390**,** e35-e36.

CHIOLERO, A. 2018. Why causality, and not prediction, should guide obesity prevention policy. *The Lancet Public Health,* 3**,** e461-e462.

COHEN, R. & PERRIER, M. 2013. *Global Sociology,* New York City, New York University Press.

COLLINS, M., KNUTTI, R., ARBLASTER, J., DUFRESNE, J.-L., FICHEFET, T., FRIEDLINGSTEIN, P., GAO, X., GUTOWSKI, W. J., JOHNS, T., KRINNER, G., SHONGWE, M., TEBALDI, C., WEAVER, A. J. & WEHNER, M. 2013. Long-term Climate Change: Projections, Commitments and Irreversibility. *In:* STOCKER, T. F., QIN, D., PLATTNER, G.-K., TIGNOR, M., ALLEN, S. K., BOSCHUNG, J., NAUELS, A., XIA, Y., BEX, V. & MIDGLEY, P. M. (eds.) *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.* Cambridge, United Kingdom and New York, NY, USA.: Cambridge University Press.

DALY, H. E. & FARLEY, J. 2011. *Ecological Economics: Principles and Applications,* Washington, DC., Island Press.

DASGUPTA, P., J.F. MORTON, D. DODMAN, B. KARAPINAR, F. MEZA, M.G. RIVERA-FERRE, A. TOURE SARR, K.E. VINCENT, 2014. Rural Areas. *In:* FIELD, C. B., V.R. BARROS, D.J. DOKKEN, K.J. MACH, M.D. MASTRANDREA, T.E. BILIR, M. CHATTERJEE, K.L. EBI, Y.O. ESTRADA, R.C. GENOVA, B. GIRMA, E.S. KISSEL, A.N. LEVY, S. MACCRACKEN, P.R. MASTRANDREA, L.L. WHITE, (ed.) *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.* Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press.

DE LA O CAMPOS, A. P., VILLANI, C., DAVIS, B. & TAKAGI, M. 2018. Ending extreme poverty in rural areas – Sustaining livelihoods to leave no one behind. Rome: FAO.

DZEBO, A., JANETSCHEK, H., BRANDI, C. & IACOBUTA, G. 2018. The Sustainable Development Goals viewed through a climate lens. *SEI Policy Brief.* Stockholm Environment Institute.

EBI, K. L. 2013. Health in the new scenarios for climate change research. *International journal of environmental research and public health,* 11**,** 30-46.

EBI, K. L., HASEGAWA, T., HAYES, K., MONAGHAN, A., PAZ, S. & BERRY, P. 2018. Health risks of warming of 1.5 °C, 2 °C, and higher, above pre-industrial temperatures. *Environmental Research Letters,* 13**,** 063007.

GBD 2017 SDG COLLABORATORS 2018. Measuring progress from 1990 to 2017 and projecting attainment to 2030 of the health-related Sustainable Development Goals for 195 countries

and territories: a systematic analysis for the Global Burden of Disease Study 2017. *Lancet,* 392**,** 2091-2138.
HAINES, A. 2017. Health co-benefits of climate action. *The Lancet Planetary Health,* 1**,** e4-e5.
HAINES, A., ALLEYNE, G., KICKBUSCH, I. & DORA, C. 2012. From the Earth Summit to Rio+20: integration of health and sustainable development. *Lancet,* 379**,** 2189-97.
HALES, S., KOVATS, R. S., LLOYD, S. J. & CAMPBELL-LENDRUM, D. (eds.) 2014. *Quantiative risk assessment of the effects of climate change on selected causes of death, 2030s and 2050s,* Geneva: WHO.
HALLEGATTE, S., BANGALORE, M., BONZANIGO, L., FAY, M., KANE, T., NARLOCH, U., ROZENBERG, J., TREGUER, D. & VOGT-SCHILB, A. 2016. Shock Waves: Managing the Impacts of Climate Change on Poverty. Washington, DC.: World Bank.
HALLEGATTE, S. & ROZENBERG, J. 2017. Climate change through a poverty lens. *Nature Climate Change,* 7**,** 250.
HASEGAWA, T., FUJIMORI, S., TAKAHASHI, K. & MASUI, T. 2015. Scenarios for the risk of hunger in the twenty-first century using Shared Socioeconomic Pathways. *Environmental Research Letters,* 10**,** 014010.
HASEGAWA, T., FUJIMORI, S., TAKAHASHI, K., YOKOHATA, T. & MASUI, T. 2016. Economic implications of climate change impacts on human health through undernourishment. *Climatic Change,* 136**,** 189-202.
HEDSTRÖM, P. 2005. *Dissecting the Social: On the Principles of Analytical Sociology,* Cambridge, Cambridge University Press.
HENNESSY, E., ORNSTEIN, J. T., ECONOMOS, C. D., HERZOG, J. B., LYNSKEY, V., COFFIELD, E. & HAMMOND, R. A. 2016. Designing an Agent-Based Model for Childhood Obesity Interventions: A Case Study of ChildObesity180. *Preventing chronic disease,* 13**,** E04-E04.
HERTEL, T. W. 2016. Food security under climate change. *Nature Clim. Change,* 6**,** 10-13.
HINKEL, J. & KLEIN, R. J. T. 2009. Integrating knowledge to assess coastal vulnerability to sea-level rise: the development of the DIVA tool. *Global Environmental Change,* 19**,** 384-395.
HOEGH-GULDBERG, O., JACOB, D., TAYLOR, M., BINDI, M., BROWN, S., CAMILLONI, I., DIEDHIOU, A., DJALANTE, R., EBI, K., ENGELBRECHT, F., GUIOT, J., HIJIOKA, Y., MEHROTRA, S., PAYNE, A., SENEVIRATNE, S. I., THOMAS, A., WARREN, R. & ZHOU, G. 2018. Impacts of 1.5°C Global Warming on Natural and Human Systems. *In:* MASSON DELMOTTE, V., ZHAI, P., PÖRTNER, H. O., ROBERTS, D., SKEA, J., SHUKLA, P. R., PIRANI, A., MOUFOUMA-OKIA, W., PÉAN, C., PIDCOCK, R., CONNORS, S., MATTHEWS, J. B. R., CHEN, Y., ZHOU, X., GOMIS, M. I., LONNOY, E., MAYCOCK, T., TIGNOR, M. & WATERFIELD , T. (eds.) *Global Warming of 1.5°C. An IPCC Special Report on the Impacts of Global Warming of 1.5°C above Pre-Industrial Levels and Related Global Greenhouse Gas Emission Pathways, in the Context of Strengthening the Global Response to the Threat of Climate Change, Sustainable Development, and Efforts to Eradicate Poverty.* In Press.
IFAD. Conference on New Directions for Smallholder Agriculture, 24-25 January 2011, Rome, IFAD HQ: Proceedings of the Conference. New Directions for Smallholder Agriculture, 2011 Rome. IFAD.
IIASA. 2018. *SSP Database (Shared Socioeconomic Pathways)* [Online]. Available: https://tntcat.iiasa.ac.at/SspDb/dsd?Action=htmlpage&page=about [Accessed 12.2.19 2019].
ISHIDA, H., KOBAYASHI, S., KANAE, S., HASEGAWA, T., FUJIMORI, S., SHIN, Y., TAKAHASHI, K., MASUI, T., TANAKA, A. & HONDA, Y. 2014. Global-scale projection and its sensitivity analysis of the health burden attributable to childhood undernutrition under the latest scenario framework for climate change research. *Environmental Research Letters,* 9**,** 064014.
JERVEN, M. 2013. *Poor Numbers: How We Are Misled By African Development Statistics and What To Do About It* Cornell, Cornell University Press.

JERVEN, M. 2018. Beyond precision: embracing the politics of global health numbers. *The Lancet,* 392**,** 468-469.
JIANG, L. & O'NEILL, B. C. 2017. Global urbanization projections for the Shared Socioeconomic Pathways. *Global Environmental Change,* 42**,** 193-199.
JONES, B. & O'NEILL, B. C. 2016. Spatially explicit global population scenarios consistent with the Shared Socioeconomic Pathways. *Environmental Research Letters,* 11.
KAPLINSKY, R. 2005. *Globaliztion, poverty, and inequality,* Cambridge, Polity Press.
KRIEGER, N. 2012. Who and What Is a "Population"? Historical Debates, Current Controversies, and Implications for Understanding "Population Health" and Rectifying Health Inequities. *The Milbank Quarterly,* 90**,** 634-681.
LISTER, R. 2004. *Poverty,* Cambridge, Polity Press.
LLOYD, S., J., BANGALORE, M., CHALABI, Z., KOVATS, R. S., HALLEGATTE, S., ROZENBERG, J., VALIN, H. & HAVLÍK, P. 2018. A Global-Level Model of the Potential Impacts of Climate Change on Child Stunting via Income and Food Price in 2030. *Environmental Health Perspectives,* 126**,** 097007.
LLOYD, S. J., KOVATS, R. S. & CHALABI, Z. 2011. Climate Change, Crop Yields, and Undernutrition: Development of a Model to Quantify the Impact of Climate Scenarios on Child Undernutrition *Environmental Health Perspectives,* 119**,** 1817-1823.
LLOYD, S. J., KOVATS, R. S. & CHALABI, Z. 2014. Undernutrition. *In:* HALES, S., KOVATS, R. S., LLOYD, S. J. & CAMPBELL-LENDRUM, D. (eds.) *Quantitative risk assessment of the effects of climate change on selected causes of death, 2030s and 2050s.* Geneva: World Health Organization.
LLOYD, S. J., KOVATS, R. S., CHALABI, Z., BROWN, S. & NICHOLLS, R. J. 2016. Modelling the influences of climate change-associated sea-level rise and socioeconomic development on future storm surge mortality. *Climatic Change,* 134**,** 441-455.
MATHERS, C. D., FAT, D. M., INOUE, M., RAO, C. & LOPEZ, A. D. 2005. Counting the dead and what they died from: an assessment of the global status of cause of death data. *Bull World Health Organ,* 83**,** 171-7.
MAZOYER, M. & ROUDART, L. 2006. *A History of World Agriculture: from the Neolithic Age to the Current Crisis,* London, Earthscan.
MCMICHAEL, A. J., WOODWARD, A. & MUIR, C. 2017. *Climate change and the health of nations: famines, fevers, and the fate of populations,* New York, Oxford University Press.
NELSON, G. C., ROSEGRANT, M. W., PALAZZO, A., GRAY, I., INGERSOLL, C., ROBERTSON, R., TOKGOZ, S., ZHU, T., SULSER, T. B., RINGLER, C., MSANGI, S. & YOU, L. 2010. Food security, farming, and climate change to 2050. Washington, DC: IFPRI.
O'NEILL, B. C., KRIEGLER, E., EBI, K. L., KEMP-BENEDICT, E., RIAHI, K., ROTHMAN, D. S., VAN RUIJVEN, B. J., VAN VUUREN, D. P., BIRKMANN, J., KOK, K., LEVY, M. & SOLECKI, W. 2017. The roads ahead: Narratives for shared socioeconomic pathways describing world futures in the 21st century. *Global Environmental Change,* 42**,** 169-180.
OTTO, I. M., BIEWALD, A., COUMOU, D., FEULNER, G., KÖHLER, C., NOCKE, T., BLOK, A., GRÖBER, A., SELCHOW, S., TYFIELD, D., VOLKMER, I., SCHELLNHUBER, H. J. & BECK, U. 2015. Socio-economic data for global environmental change research. *Nature Climate Change,* 5**,** 503.
PATEL, R. 2009. Food sovereignty. *The Journal of Peasant Studies,* 36**,** 663-706.
POGGE, T. 2010. *Politics as Usual,* Cambridge, Polity.
RAO, N. D., SAUER, P., GIDDEN, M. & RIAHI, K. 2019. Income inequality projections for the Shared Socioeconomic Pathways (SSPs). *Futures,* 105**,** 27-39.
RIAHI, K., VAN VUUREN, D. P., KRIEGLER, E., EDMONDS, J., O'NEILL, B. C., FUJIMORI, S., BAUER, N., CALVIN, K., DELLINK, R., FRICKO, O., LUTZ, W., POPP, A., CUARESMA, J. C., KC, S., LEIMBACH, M., JIANG, L., KRAM, T., RAO, S., EMMERLING, J., EBI, K., HASEGAWA, T., HAVLIK, P., HUMPENÖDER, F., DA SILVA, L. A., SMITH, S., STEHFEST, E., BOSETTI, V., EOM, J., GERNAAT, D., MASUI, T., ROGELJ, J., STREFLER, J., DROUET, L., KREY, V., LUDERER, G., HARMSEN, M., TAKAHASHI, K., BAUMSTARK, L., DOELMAN, J. C., KAINUMA, M., KLIMONT, Z., MARANGONI,

G., LOTZE-CAMPEN, H., OBERSTEINER, M., TABEAU, A. & TAVONI, M. 2017. The Shared Socioeconomic Pathways and their energy, land use, and greenhouse gas emissions implications: An overview. *Global Environmental Change,* 42**,** 153-168.
RIBOT, J. 2014. Cause and response: vulnerability and climate in the Anthropocene. *The Journal of Peasant Studies,* 41**,** 667-705.
ROY, J., TSCHAKERT, P., WAISMAN, H., ABDUL HALIM, S., ANTWI-AGYEI, P., DASGUPTA, P., HAYWARD, B., KANNINEN, M., LIVERMAN, D., OKEREKE, C., PINHO, P. F., RIAHI, K. & SUAREZ RODRIGUEZ, A. G. 2018. Sustainable development, poverty eradication and reducing inequalities. *In:* V. MASSON-DELMOTTE, P. Z., H. O. PÖRTNER, D. ROBERTS, J. SKEA, P. R. SHUKLA, A. PIRANI, W. MOUFOUMA-OKIA, C. PÉAN, R. PIDCOCK, S. CONNORS, R. B. R. MATTHEWS, Y. CHEN, X. ZHOU, M. I. GOMIS, E. LONNOY, T. MAYCOCK, M. TIGNOR, T. WATERFIELD (ed.) *Global warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°Cabove pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty.* In Press.
SENNETT, R. 2018. *Building and Dwelling: Ethics for the City*, Allen Lane.
SIETZ, D., ORDOÑEZ, J. C., KOK, M. T. J., JANSSEN, P., HILDERINK, H. B. M., TITTONELL, P. & VAN DIJK, H. 2017. Nested archetypes of vulnerability in African drylands: where lies potential for sustainable agricultural intensification? *Environmental Research Letters,* 12**,** 095006.
SMITH, K. R., WOODWARD, A., CAMPBELL-LENDRUM, D., CHADEE, D. D., HONDA, Y., LIU, Q., OLWOCH, J. M., REVICH, B. & SAUERBORN, R. 2014. Human health: impacts, adaptation, and co-benefits. *In:* FIELD, C. B., V.R. BARROS, D.J. DOKKEN, K.J. MACH, M.D. MASTRANDREA, T.E. BILIR, M. CHATTERJEE, K.L. EBI, Y.O. ESTRADA, R.C. GENOVA, B. GIRMA, E.S. KISSEL, A.N. LEVY, S. MACCRACKEN, P.R. MASTRANDREA, L.L. WHITE, (ed.) *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.* Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press.
SMITH, L. C. & HADDAD, L. 2015. Reducing Child Undernutrition: Past Drivers and Priorities for the Post-MDG Era. *World Development,* 68**,** 180-204.
SVEDBERG, P. 2000. *Poverty and Undernutrition: Theory, Measurement, and Policy,* Oxford, Oxford University Press.
TIMMERMANN, C. & FÉLIX, G. F. 2015. Agroecology as a vehicle for contributive justice. *Agriculture and Human Values,* 32**,** 523-538.
UNICEF 1990. Strategy for the improvement of nutrition in children and women in developing countries. New York: UNICEF.
UNISDR 2015. Sendai Framework for Disaster Risk Reduction 2015 - 2030. Geneva: The United Nations Office for Disaster Risk Reduction.
UNITED NATIONS 2015a. Paris Agreement. United Nations.
UNITED NATIONS 2015b. Transforming Our World: The 2030 Agenda for Sustainable Development. New York: United Nations.
WATTS, N., ADGER, W. N., AGNOLUCCI, P., BLACKSTOCK, J., BYASS, P., CAI, W., CHAYTOR, S., COLBOURN, T., COLLINS, M., COOPER, A., COX, P. M., DEPLEDGE, J., DRUMMOND, P., EKINS, P., GALAZ, V., GRACE, D., GRAHAM, H., GRUBB, M., HAINES, A., HAMILTON, I., HUNTER, A., JIANG, X., LI, M., KELMAN, I., LIANG, L., LOTT, M., LOWE, R., LUO, Y., MACE, G., MASLIN, M., NILSSON, M., ORESZCZYN, T., PYE, S., QUINN, T., SVENSDOTTER, M., VENEVSKY, S., WARNER, K., XU, B., YANG, J., YIN, Y., YU, C., ZHANG, Q., GONG, P., MONTGOMERY, H. & COSTELLO, A. 2015. Health and climate change: policy responses to protect public health. *Lancet,* 386**,** 1861-914.
WATTS, N., AMANN, M., ARNELL, N., AYEB-KARLSSON, S., BELESOVA, K., BERRY, H., BOULEY, T., BOYKOFF, M., BYASS, P., CAI, W., CAMPBELL-LENDRUM, D., CHAMBERS, J., DALY, M., DASANDI, N., DAVIES, M., DEPOUX, A., DOMINGUEZ-SALAS, P., DRUMMOND, P., EBI, K. L.,

EKINS, P., MONTOYA, L. F., FISCHER, H., GEORGESON, L., GRACE, D., GRAHAM, H., HAMILTON, I., HARTINGER, S., HESS, J., KELMAN, I., KIESEWETTER, G., KJELLSTROM, T., KNIVETON, D., LEMKE, B., LIANG, L., LOTT, M., LOWE, R., SEWE, M. O., MARTINEZ-URTAZA, J., MASLIN, M., MCALLISTER, L., MIKHAYLOV, S. J., MILNER, J., MORADI-LAKEH, M., MORRISSEY, K., MURRAY, K., NILSSON, M., NEVILLE, T., ORESZCZYN, T., OWFI, F., PEARMAN, O., PENCHEON, D., PYE, S., RABBANIHA, M., ROBINSON, E., ROCKLOV, J., SAXER, O., SCHUTTE, S., SEMENZA, J. C., SHUMAKE-GUILLEMOT, J., STEINBACH, R., TABATABAEI, M., TOMEI, J., TRINANES, J., WHEELER, N., WILKINSON, P., GONG, P., MONTGOMERY, H. & COSTELLO, A. 2018. The 2018 report of the Lancet Countdown on health and climate change: shaping the health of nations for centuries to come. *Lancet,* 392**,** 2479-2514.

WHO 2018. World health statistics 2018: monitoring health for the SDGs, sustainable development goals. . Geneva: WHO.

WISNER, B., BLAIKIE, P., CANNON, T. & DAVIS, I. 2004. *At Risk,* Oxon, Routledge.

WITTGENSTEIN CENTRE FOR DEMOGRAPHY AND GLOBAL HUMAN CAPITAL. 2017. *Wittgenstein Centre Data Explorer Version 1.2* [Online]. Vienna. Available: http://www.oeaw.ac.at/vid/dataexplorer/ [Accessed July 7 2017].

WRIGHT, E. O. 2010. *Envisioning Real Utopias,* London, Verso.