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Supplementary appendix

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Appendix to *Priority climate and health modeling needs*

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Table of contents:

Annex 1: Survey and participants

Workshop goals and approach

Overarching goal of the workshop:
Provide consensus statements on priority modeling needs to further understand and quantify the health risks of climate change and risk reduction strategies, to inform policy and decision-making at national to international scales. These consensus statements will be used by Wellcome Trust to inform their investment strategies.

Approach:
A snowball sampling approach identified modelers of the current impacts and future risks of climate change and health, and of the upstream drivers of climate-sensitive health outcomes. This email survey is intended to identify priority opportunities for increasing understanding of how climate change could further alter the magnitude and pattern of health risks, and for increasing the policy relevance of model outputs. The goal is to identify areas of consensus and to frame in-person discussions through which additional priority research areas may emerge. A workshop proceedings paper will summarize the discussion, highlight areas of consensus, and outline implications for potential investments.

The questions cover a broad range of topics around climate change and health, not all of which will be relevant to each participant's area of expertise. Each participant is invited to complete those questions of interest and/or relevance.

Scope:
Relevant modeling efforts: the survey and workshop will focus on three main areas:

- **Furthering understanding via modeling of the current impacts and future risks of weather, climate variability, and climate change for human health and well-being.* This includes models that:**
  - **Describe current relationships, particularly for understudied health outcomes.**
  - **Project the magnitude and pattern of future health burdens, considering social, economic, and demographic variables important to population health, and considering a range of possible mitigation and adaptation pathways.**
  - **Facilitate the integration of health into integrated assessment modeling efforts, agriculture/food security modeling efforts, and ecosystem service modeling, as nascent efforts have demonstrated the policy relevance of incorporating health into modeling primarily led by other sectors.**
- **Increasing the policy impact of weather, climate variability, climate change and human health impact modeling by:**
  - **Focusing on appropriate time horizons for decision-making. For much of public health programming, time horizons range from sub-seasonal to annual to, at most, decadal. Time horizons for physical infrastructure are longer, from 50 – 100 years.**
  - **Ensuring a focus on underserved populations and explicit consideration of diversity, equity, and inclusion, including determination of the data**

resolution needed to address these considerations in modeling efforts.

- **Identifying opportunities for multi-model intercomparisons and other approaches to synthesize results across modeling efforts.**
- **Incorporating policymakers and other stakeholders in modeling processes to increase their policy relevance.**
- **Allowing for continuous learning and quality improvement through sustained investment and engagement with scientists, practitioners, and stakeholders.**

- **Outlining the funding and modeling infrastructure required to support these modeling efforts, including data needs for understudied health outcomes, common platforms, required diversity of efforts, education and training for interdisciplinary modeling work, approaches to facilitate transdisciplinary modeling, and best practices for policymaker and other stakeholder engagement and translation of findings.**

*** Note the survey and workshop will not include detection and attribution because that is part of another Wellcome Trust activity**

1. Contact information

Name

Email Address

Wellcome Modeling Climate and Health

Pre-workshop survey questions

Furthering understanding of the current impacts and future risks of weather, climate variability, and climate change for human health and well-being.

Wellcome Modeling Climate and Health

Quantify the current magnitude and burden of climate-sensitive health outcomes

2. Please list your top 5 priority understudied health outcomes. This link has a non-comprehensive list that can be used for consideration; each category includes both morbidity and mortality.

First priority:

Second priority:

Third priority:

Fourth priority:

Fifth priority:

3. In your opinion, what is needed to advance modeling of the outcomes you chose? If you know of existing modeling approaches, please include them in your answer. If new models need to be developed, please outline the approach(es) you would advocate.

4. Please outline where (in terms of specific outcomes, populations, geographies, and/or disciplines) new modeling approaches are urgently needed to quantify the current magnitude and burden of climate-sensitive health outcomes.

5. In your opinion, what is the highest priority activity in modeling the health impacts of weather, climate variability, and climate change?

6. Are there any efforts that you would consider having high potential for significantly advancing modeling of climate change impacts on health and wellbeing to prioritize for funding investments (i.e., high potential "shovel ready" efforts primarily constrained by lack of resources)?

Wellcome Modeling Climate and Health

Project the magnitude and pattern of health risks under a range of climate and development scenarios

7. When robust observational data are not available, what data and methods do you use to establish a baseline for morbidity / mortality, population, demographic structure, and other variables for projecting the extent to which climate change could alter the magnitude and pattern of health burdens?

8. Please rank the following SSP-RCP scenarios for use in climate and health modeling:

- SSP1-1.9
- SSP1-2.6
- SSP2-4.5
- SSP3-7.0
- SSP5-8.5

9. Please outline your preferred adaptation scenarios, including qualitative narratives and quantifications, that can be applied across the health risks of climate change.

First preferred:

Second preferred:

Third preferred:

Add additional preferred scenarios here (if more than 3):

10. Please list your priorities for multi-model intercomparisons that could generate new insights into climate change and health risks under a range of climate and development scenarios, and outline requirements to support these intercomparison efforts.

First priority and requirements:

Second priority and requirements:

Third priority and requirements:

Additional priorities and requirements:

11. Please outline advances you think are needed to provide one or more update(s) of the World Health Organization Quantitative Risk Assessment published in 2014 and make the next assessment(s) more inclusive, comprehensive, and impactful.

12. In your opinion, what is the highest priority activity in modeling the health impacts of weather, climate variability, and climate change, and why, and what would be required to realize this activity's potential?

Wellcome Modeling Climate and Health

Facilitate the two-way integration of health into other modeling efforts

13. Please describe priority advances for integrating population health into integrated assessment, ecosystem, food security, and other models of the potential consequences of climate change.

First priority:

Second priority:

Third priority:

Additional priorities:

14. Please describe priority advances for integrating integrated assessment, ecosystem, food security, and other models into population health models of the potential consequences of climate change.

First priority:

Second priority:

Third priority:

Additional priorities:

15. Please outline preferred approaches to calculating health damage functions that could be incorporated into integrated assessment models.

First preferred:

Second preferred:

Third preferred:

Additional preferred approaches:

16. Please specify high priority health damage functions that would best contribute to integrated assessment modeling efforts (1 = highest). Enter up to 10.

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Wellcome Modeling Climate and Health

Increasing the policy impact of weather, climate variability, climate change and human modeling

17. Please outline the time horizons for projections and/or temperature thresholds that you believe to be most important for stakeholders.

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3:
4:
5:

18. Please outline preferred **new data collection methods** for ensuring a focus on underserved populations and explicit consideration of diversity, equity, and inclusion.

19. Please outline preferred **new modeling methods** for ensuring a focus on underserved populations and explicit consideration of diversity, equity, and inclusion.

20. Please outline preferred **new stakeholder engagement methods** for ensuring a focus on underserved populations and explicit considerations of diversity, equity, and inclusion.

21. Please identify opportunities for multi-model intercomparisons and other approaches to synthesize results across modeling efforts and outline high priority activities in this area.

Wellcome Modeling Climate and Health

Modeling infrastructure needs

22. Please outline modeling infrastructure needs, including (but not limited to):
a. Data needs for understudied health outcomes;
b. Common modeling platforms and what additions would improve their relevance and utility;
c. Approaches to facilitate transdisciplinary modeling

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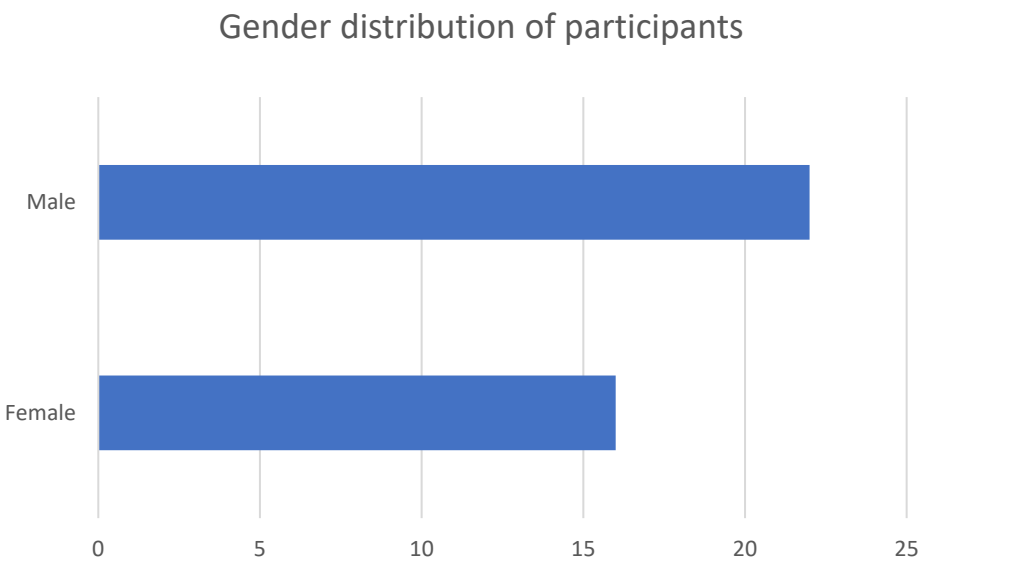
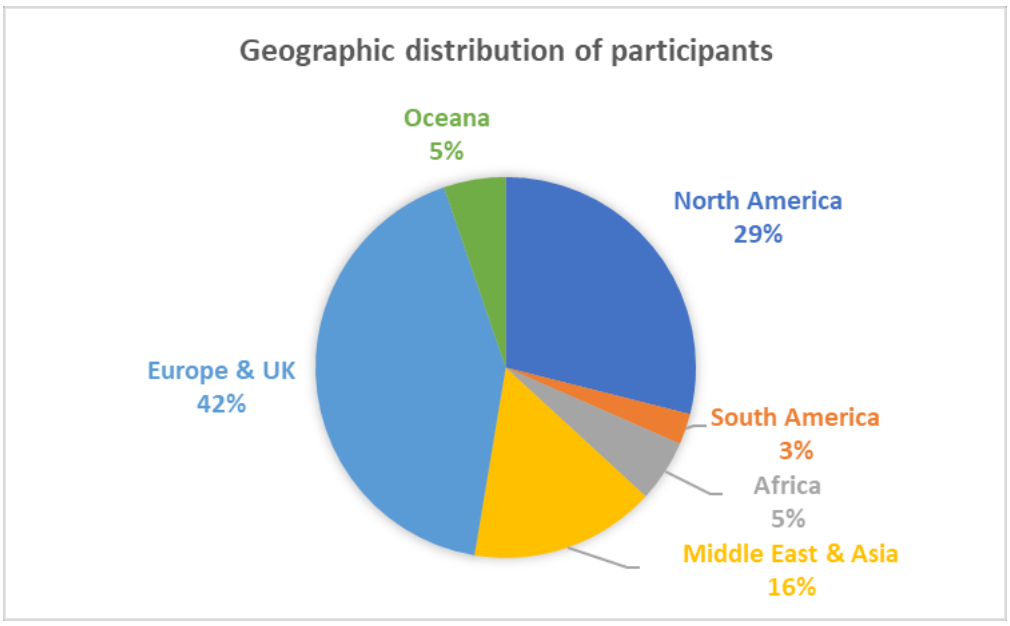
3:
4:
5:

23. Comments or additional thoughts:

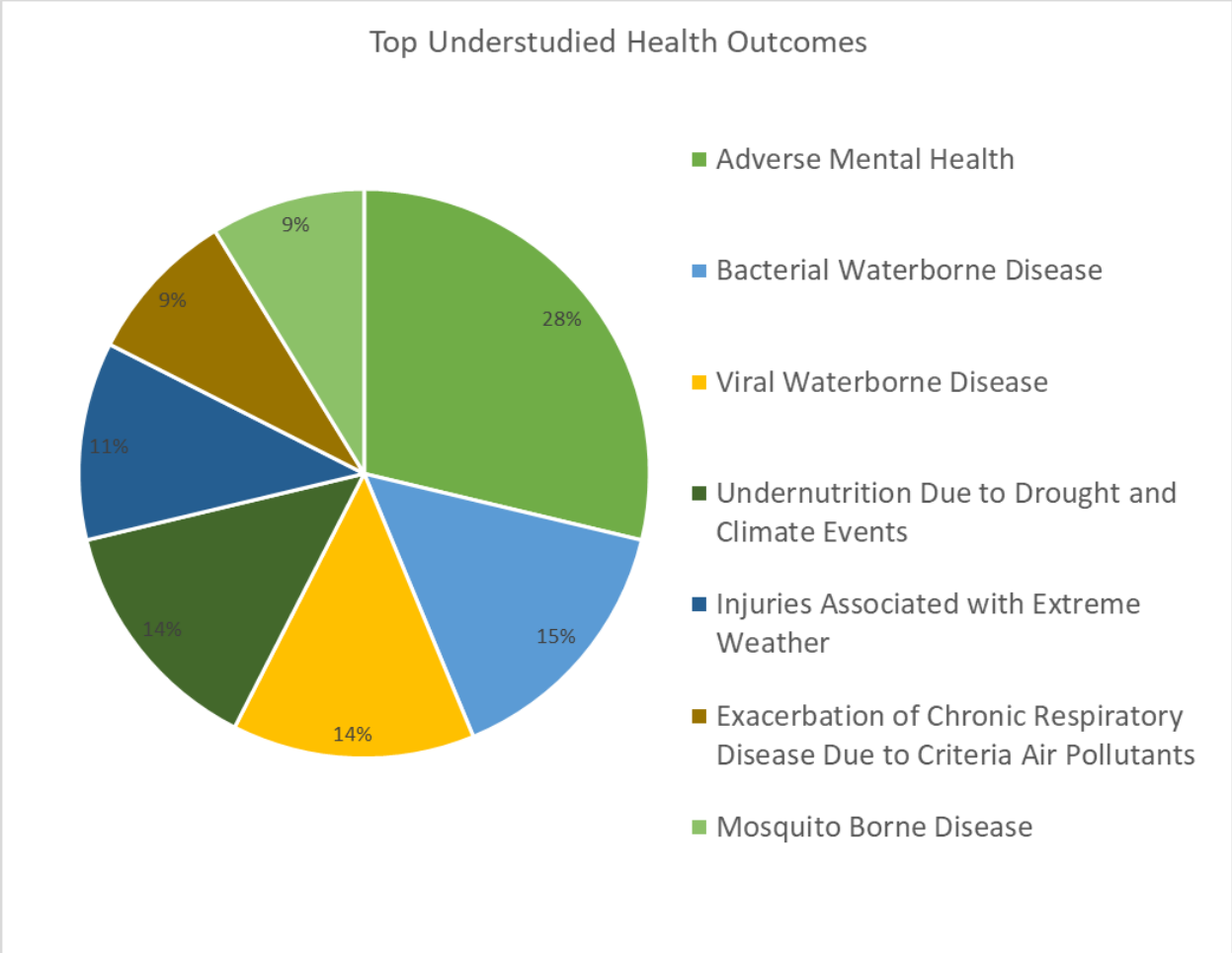
(2 Figures): Gender and Geographic distribution of survey respondents



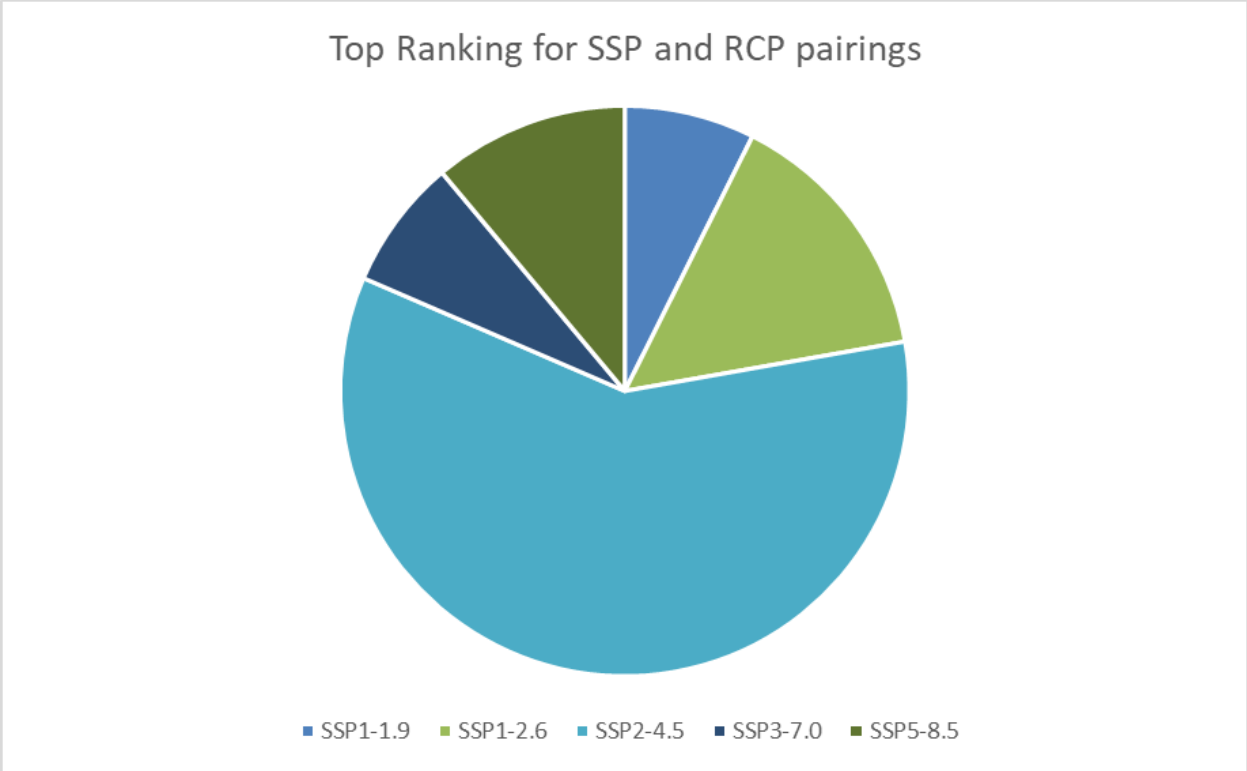


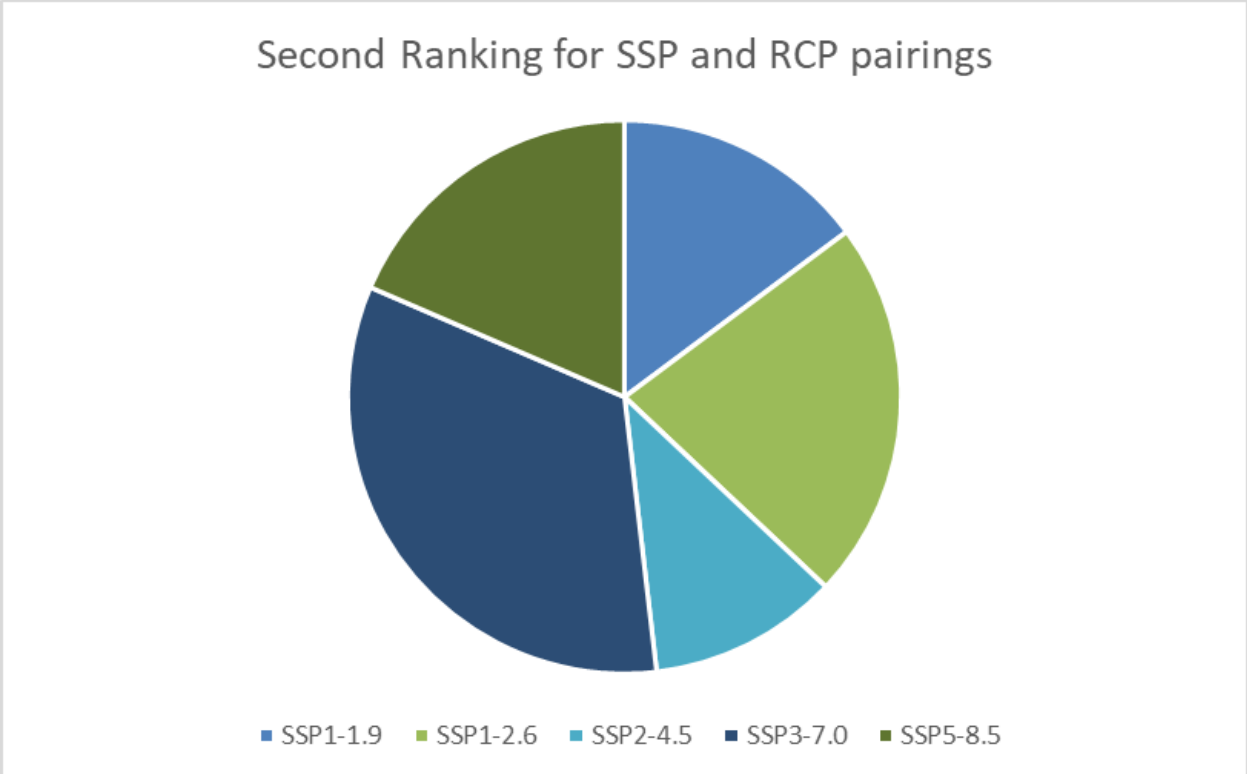
Annex 2: Survey analysis figures

(Figure 1) describes the most frequent survey responses to question 2; please list your top 5 priority understudied health outcomes. Due to the quantity of available studies related to climate -induced heat-related health outcomes, heat-related responses were removed from this figure. Excluding heat-related health outcomes, the most common responses included adverse mental health outcomes (28%), bacterial waterborne disease outcomes (15%), viral waterborne disease outcomes (14%), undernutrition due to drought and climate events (14%), injuries associated with extreme weather (11%), exacerbation of chronic respiratory disease due to criteria air pollutants (9%) and mosquito borne disease outcomes (9%).



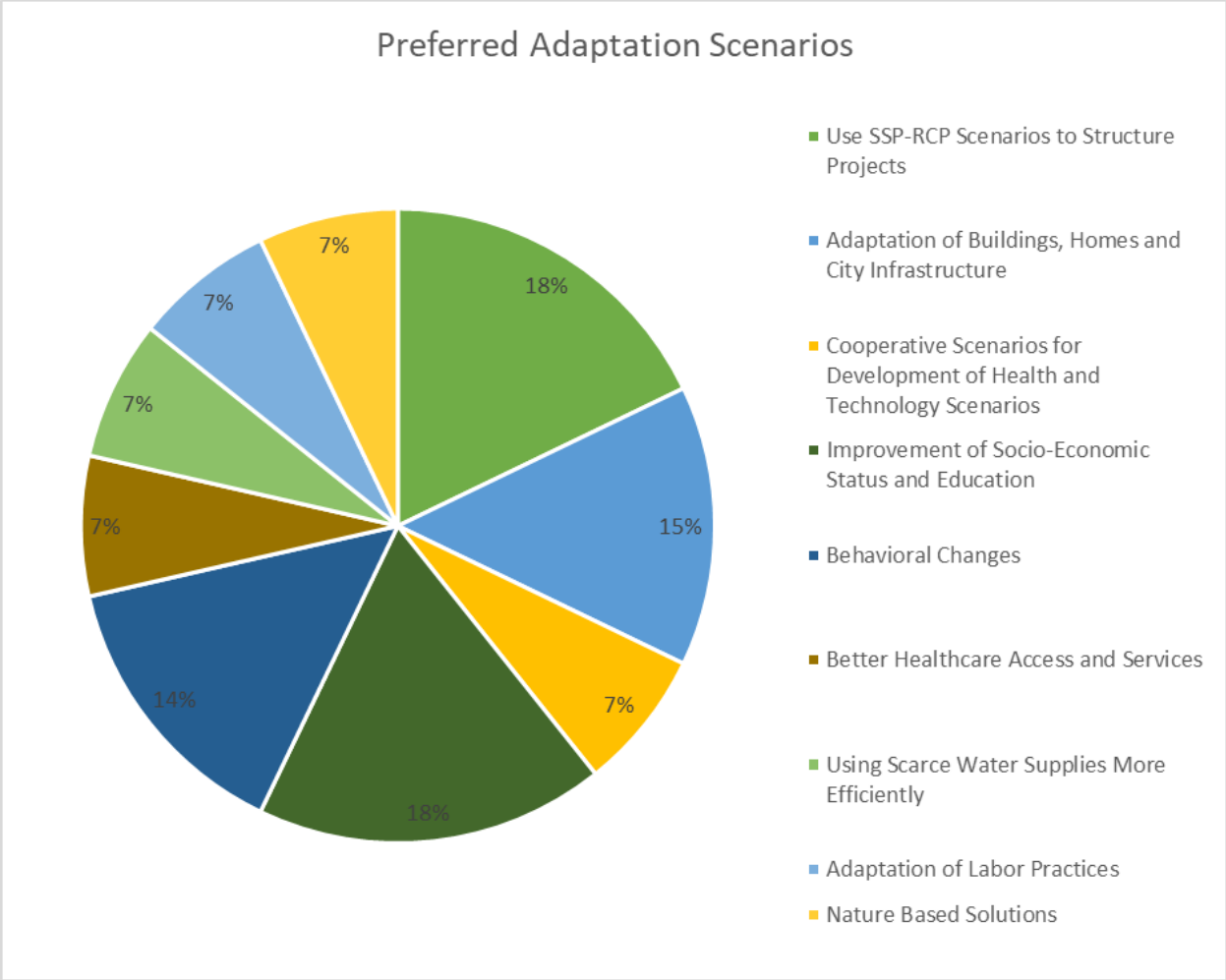
(Figure 2 and 3) describe the most frequent survey responses to question 8; please rank the following SSP-RCP scenarios for use in climate and health modeling. (Figure 2) represents the primary ranking of the most used SSP-RCP pairings, while (Figure 3) represents the secondary ranking of most commonly used SSP-RCP pairings. The most frequently used primary SSP-RCP pairing was overwhelmingly SSP2-4.5, while the most frequently used secondary SSP-RCP pairing was more diverse, with both SSP1-2.6, SSP3-7.0 and SSP5-8.5 being used.



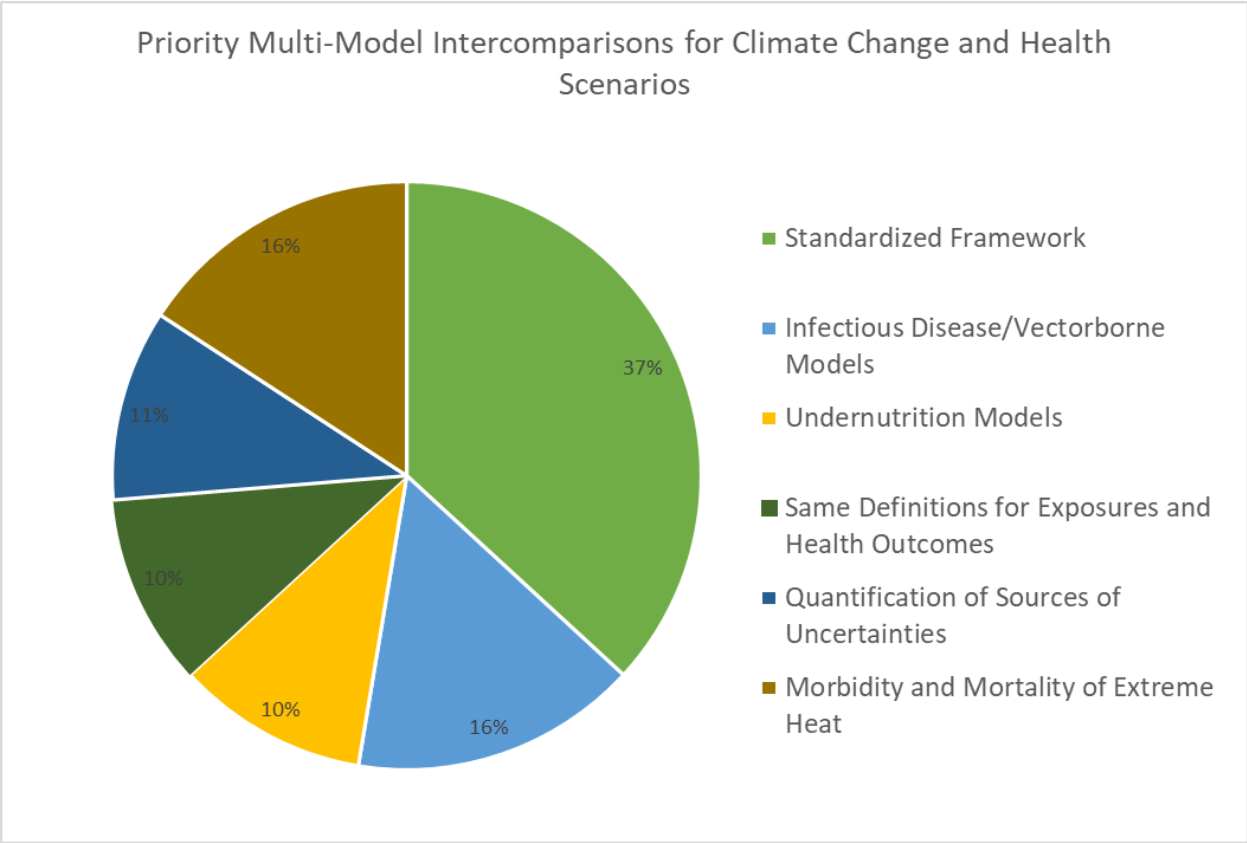


(Figure 4) describes the most frequent survey responses to question 9; please outline your preferred adaptation scenarios, including qualitative narratives and quantifications, that can be applied across the health risks of climate change. The most common responses included use of SSP-RCP scenarios to

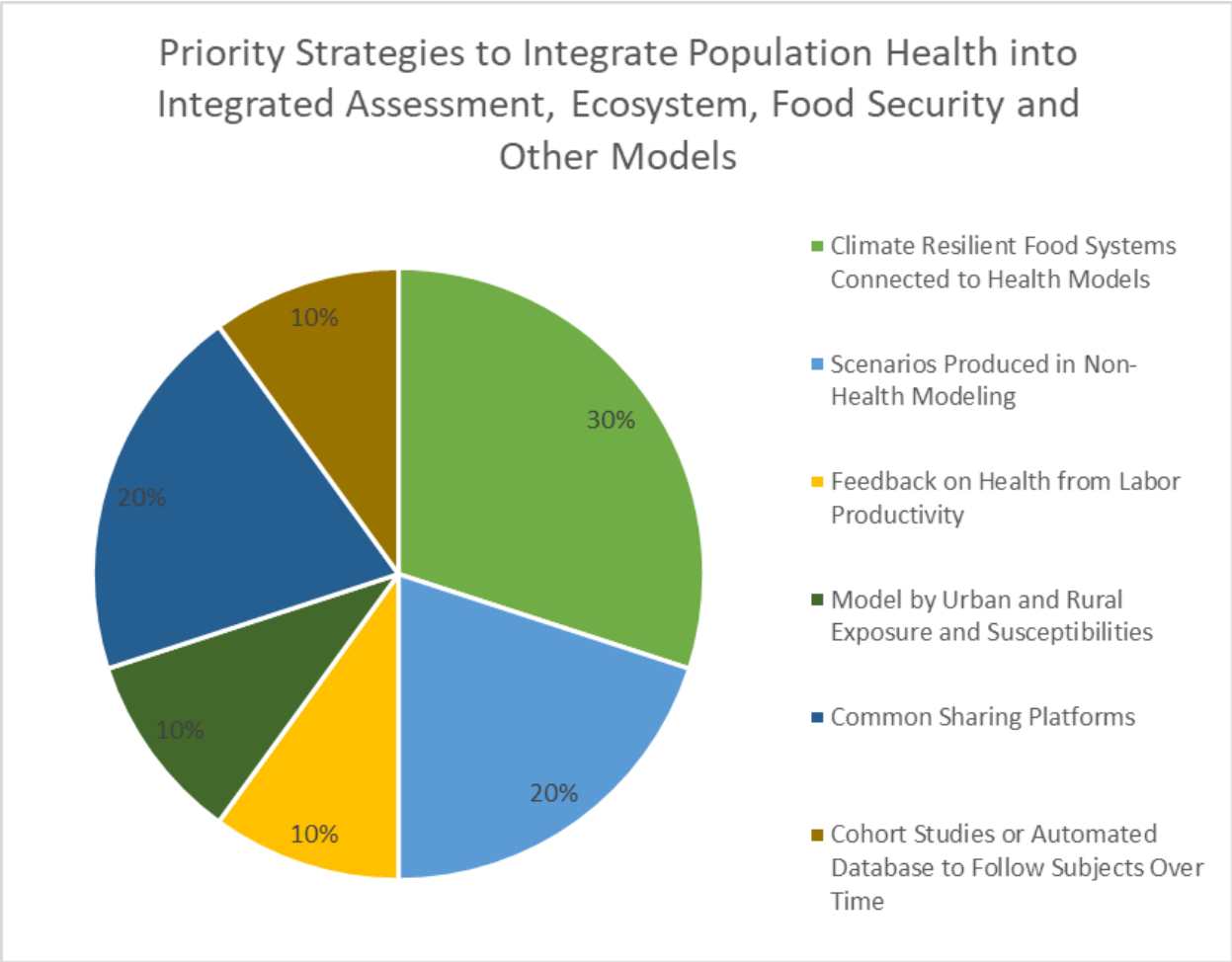
structure projects (18%), improvement of socio-economic status and education (18%), adaptation of buildings, homes, and city infrastructure (15%), behavioral changes (14%), cooperative scenarios for development of health and technology scenarios (7%), better healthcare access and services (7%), using scarce water supplies more efficiently (7%) and nature-based solutions (7%).



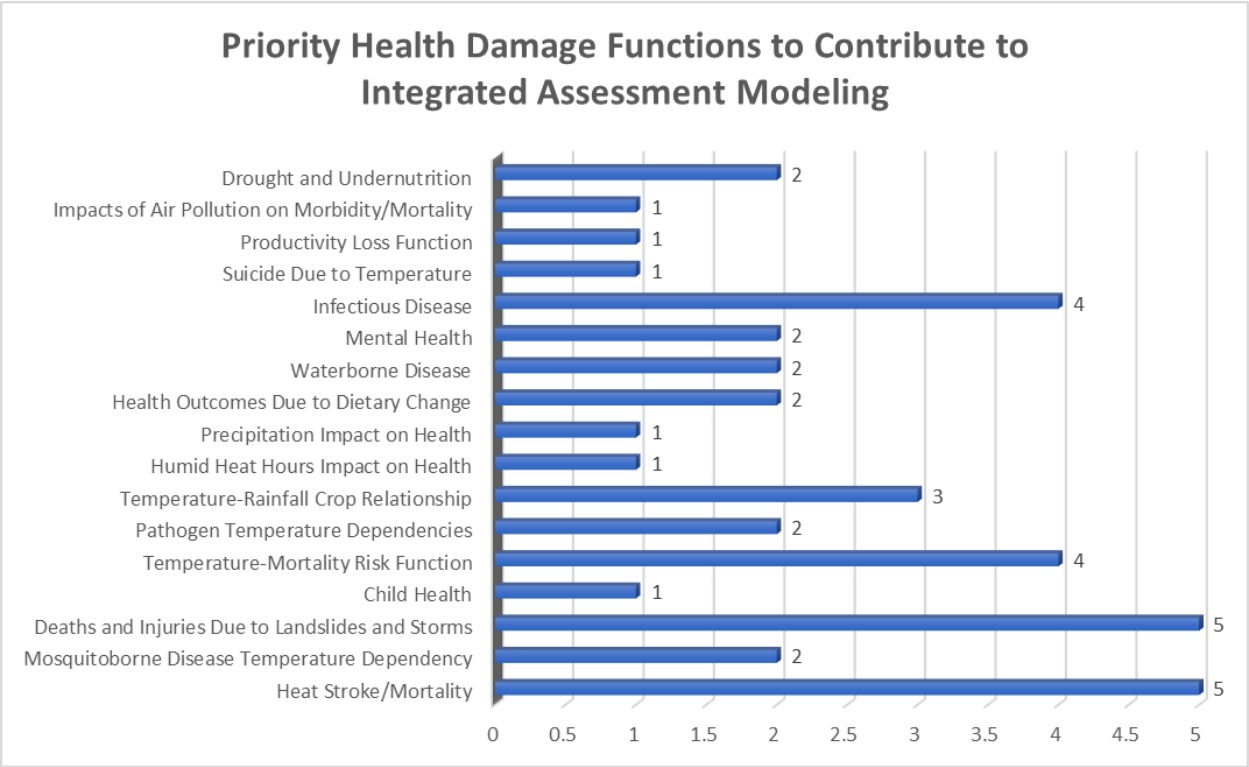
(Figure 5) describes the most frequent survey responses from question 10; please list your priorities for multi-model intercomparisons that could generate new insights into climate change and health risks under a range of and development scenarios, and outline requirements to support these intercomparison efforts. The most common responses included standardized frameworks (37%), infectious disease and vectorborne disease models (16%), morbidity and mortality of extreme heat (16%), quantification of sources of uncertainties (11%), undernutrition models (10%), and having the same definitions for exposures and health outcomes (10%).



(Figure 6) describes the most frequent survey responses for question 13; please describe priority advances for integrating population health into integrated assessment, ecosystem, food security, and other models of the potential consequences of climate change. The most common responses included climate resilient food systems connected to health models (30%), scenarios produced in non-health modeling (20%), common sharing platforms (20%), model by urban and rural exposure and susceptibilities (10%), feedback on health from labor productivity (10%) and cohort studies or automated database to follow subjects over time (10%).



(Figure 7) describes the most frequent survey responses for question 16; please specify high priority health damage functions that would best contribute to integrated assessment modeling efforts (1 = highest). Enter up to ten. The most common answers included deaths and injuries due to landslides and storms (5), heat stroke and mortality (5), infectious disease (4), temperature-mortality risk functions (4) and temperature-rainfall crop relationships (3).


Priority Health Damage Functions to Contribute to Integrated Assessment Modeling
Drought and Undernutrition
Impacts of Air Pollution on Morbidity/Mortality
Productivity Loss Function
Suicide Due to Temperature
Infectious Disease
Mental Health
Waterborne Disease
Health Outcomes Due to Dietary Change
Precipitation Impact on Health
Humid Heat Hours Impact on Health
Temperature-Rainfall Crop Relationship
Pathogen Temperature Dependencies
Temperature-Mortality Risk Function
Child Health
Deaths and Injuries Due to Landslides and Storms
Mosquitoborne Disease Temperature Dependency
Heat Stroke/Mortality
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Annex 3: Understudied health outcomes (survey responses)

Wellcome Modeling Climate and Health				
Please list your top 5 priority understudied health outcomes. This link has a non-comprehensive list that can be used for consideration; each category includes both morbidity and mortality.				
First priority:	Second priority:	Third priority:	Fourth priority:	Fifth priority:
Effects of loss of biodiversity on well being	Effects of being confined in air-conditioned buildings on well being	Effects of climate change on mental health	Effects of heat on indoor labor productivity	Effects of climate change on food borne diseases
Mental illness and extreme weather events	Chronic heat exposure	Respiratory disease and aeroallergens	Waterborne diseases	Mental health and displacement
Links with biodiversity (including vectors)	Mental health with natural solutions	Health as a formal ecosystem service	Improved vector modeling	Multi-benefit adaptation for health
Mental health associated with extreme weather events	Water-borne diseases associated with changes in temperature and precipitation	Health outcomes associated with chronic heat exposure	Undernutrition associated with extreme weather events	Exacerbations of chronic respiratory disease associated with air pollution
Mental health	Injuries	Heatstroke	Urinary system diseases	DALYs
Exacerbations of chronic mental illness associated with extreme weather events	Parasitic waterborne disease associated with changes in temperature and precipitation	Mosquito-borne diseases associated with changes in temperature and precipitation	Undernutrition associated with drought	Exacerbations of chronic respiratory disease associated with aeroallergen exposure

Exacerbation of health conditions leading to deaths brought forward from non-optimum temperatures	Heatwave mortality and morbidity	Health issues arising from extreme events like flooding and storms	Emerging infectious and vector borne diseases	Mental health impacts following extreme events
Viral waterborne disease associated with changes in temperature and precipitation	Bacterial waterborne disease associated with changes in temperature and precipitation	Parasitic waterborne disease associated with changes in temperature and precipitation	Exacerbations of chronic mental illness associated with extreme weather events	Undernutrition associated with drought
Health outcomes associated with chronic heat exposure	Unintentional injuries associated with acute heat exposure	Exacerbations of chronic respiratory disease associated with criteria air pollutant exposure	Exacerbations of chronic respiratory disease associated with aeroallergen exposure	Mosquito-borne diseases associated with changes in temperature and precipitation
Acute heat illness (heat exhaustion and heat stroke) associated with acute heat exposure	Exacerbations of chronic respiratory disease associated with criteria air pollutant exposure	Bacterial waterborne disease associated with changes in temperature and precipitation	Injuries associated with extreme weather events	Exacerbations of chronic mental illness associated with extreme weather events
Undernutrition amongst food producers	Pregnancy outcomes and extreme heat	Health outcomes associated with chronic heat exposure	Adverse mental health associated with involuntary displacement	Health impacts associated with water scarcity
Acute heat illness (heat exhaustion and heat stroke) associated with acute heat exposure	Mosquito-borne diseases associated with changes in temperature and precipitation	Bacterial waterborne disease associated with changes in temperature and precipitation	Health outcomes associated with chronic heat exposure	Exacerbations of chronic mental illness associated with extreme weather events

Maternal and newborn health	Waterborne diseases	Injuries associated with extreme weather events	Undernutrition associated with drought	Adverse mental health associated with involuntary displacement
Acute heat illness	Chronic heat exposure	Zoonotic diseases	Viral waterborne disease	Adverse mental health associated with involuntary displacement
Bacterial waterborne diseases	Tick borne	Viral waterborne	Displacement stress	Mental health, broadly
Injuries associated with extreme weather events	Pregnancy outcomes associated with acute heat exposure	future prediction models of the various health impacts	Health outcomes associated with chronic heat exposure	Exacerbations of chronic respiratory disease associated with criteria air pollutant exposure
Mental health	Indigenous health	NCDs		
Diarrheal disease	Heat-related morbidity	Heat impacts in children	Neglected tropical diseases	
Acute heat illness associated with acute heat exposure	Undernutrition associated with drought and other climate change events	Mosquito-borne diseases associated with climate change	Health outcomes associated with chronic heat exposure	Adverse mental health associated with involuntary displacement
Neglected tropical diseases	Waterborne diseases	Unintentional injuries related to extreme events	Child nutrition	Urban heat related mortality and morbidity
Water-borne diarrheal diseases	Mental health	NTDs	Soil-borne pathogens (helminths)	Pandora viruses
Morbidity (*e.g.,* hospitalizations) in high-risk populations associated with extreme weather events	Perinatal health - preterm birth, stillbirth - with extreme weather events and indirect impacts	Mental health - direct impacts of extreme weather events		

Humid heat stress	High nighttime temperatures	Geographic range of disease vectors (*e.g.,* mosquitos)	Water quality	Heat/air quality compound events
Mosquito-borne diseases associated with changes in temperature and precipitation	Tick-borne disease associated with changes in temperature and precipitation	Parasitic waterborne disease associated with changes in temperature and precipitation	Viral waterborne disease associated with changes in temperature and precipitation	Undernutrition associated with drought
Neglected tropical diseases	Waterborne diseases	Unintentional injuries related to extreme events	Mental health	
Health outcomes in the global south (*e.g.* Africa)	Health outcomes of marginalized groups (*e.g.* refugees)	Health outcomes of vulnerable groups (*e.g.* poor)	Mental health issues	Health outcomes in threatened island states
Adverse mental health associated with involuntary displacement	Undernutrition associated with climate-induced migration	Undernutrition associated with hydrometeorological extremes (drought but also others)	Undernutrition mediated by food system disruptions	Bacterial waterborne disease associated with changes in temperature and precipitation
Health outcome due to climate change-attributable undernutrition	Health outcome due to climate change-attributable poverty	Health outcome due to extreme climate events	Health outcome due to associated with heat exposure	Workplace heat-related illness
Exacerbation of mental health illness	Exacerbations of chronic respiratory, cardiovascular, renal, and metabolic (*e.g.,* diabetes) disease associated with acute heat exposure	Waterborne diseases from increasing temperatures	Exacerbations of chronic respiratory disease from air pollution	Changes in autoimmune disease response from chronic heat exposure

Interconnected impacts of multiple health threats with vulnerability	Fungal pathogens	Non-vector-borne zoonoses	Emerging vector-borne diseases in temperate regions	Waterborne illnesses
Mental health/cognitive decline due to migration	Impacts on childhood development due to migration	Impacts on physical health due to migration	Health impacts of chronic heat exposure	Injuries (road traffic) associated with heat exposure