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Forecasting the Global Burden of Disease Study

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Forecasting GBD – Overview

- **1997:** Forecasting mortality and disability 1990-2020
- **2018:** Forecasting mortality, life expectancy and risk attributable burden – better/worse scenarios (type 1)
- **2020:** Forecasting populations to 2100
- **2023:** Forecasting 370 causes, deaths, YLLs, YLDs, DALYs, incidence, prevalence, life expectancy, healthy life expectancy (HALE) – target scenarios with avoidable future burden 2020-2050
- **2023:** India subnational forecasts

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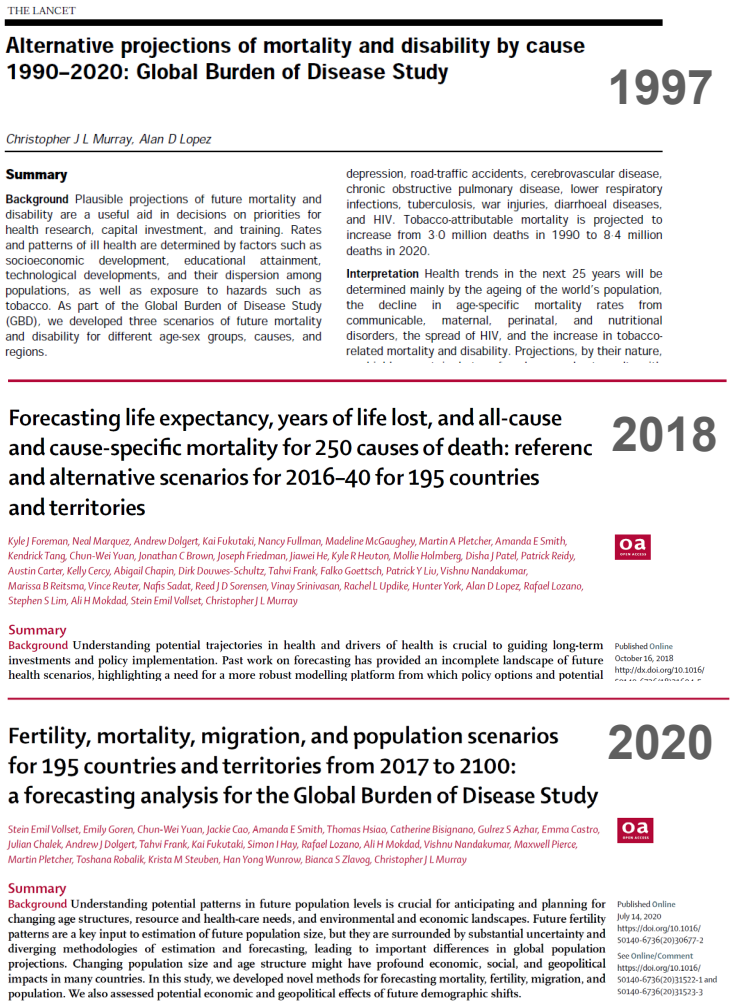


THE LANCET

Alternative projections of mortality and disability by cause 1990–2020: Global Burden of Disease Study — **1997**

Christopher J L Murray, Alan D Lopez

Summary

Background Plausible projections of future mortality and disability are a useful aid in decisions on priorities for health research, capital investment, and training. Rates and patterns of ill health are determined by factors such as socioeconomic development, educational attainment, technological developments, and their dispersion among populations, as well as exposure to hazards such as tobacco. As part of the Global Burden of Disease Study (GBD), we developed three scenarios of future mortality and disability for different age-sex groups, causes, and regions.

depression, road-traffic accidents, cerebrovascular disease, chronic obstructive pulmonary disease, lower respiratory infections, tuberculosis, war injuries, diarrhoeal diseases, and HIV. Tobacco-attributable mortality is projected to increase from 3·0 million deaths in 1990 to 8·4 million deaths in 2020.

Interpretation Health trends in the next 25 years will be determined mainly by the ageing of the world's population, the decline in age-specific mortality rates from communicable, maternal, perinatal, and nutritional disorders, the spread of HIV, and the increase in tobacco-related mortality and disability. Projections, by their nature,

Forecasting life expectancy, years of life lost, and all-cause and cause-specific mortality for 250 causes of death: referenc and alternative scenarios for 2016–40 for 195 countries and territories — **2018**

Kyle J Foreman, Neal Marquez, Andrew Dolgert, Kai Fukutaki, Nancy Fullman, Madeline McGaughey, Martin A Pletcher, Amanda E Smith, Kendrick Tang, Chun-Wei Yuan, Jonathan C Brown, Joseph Friedman, Jiawei He, Kyle R Heuton, Mollie Holmberg, Disha J Patel, Patrick Reidy, Austin Carter, Kelly Cercy, Abigail Chapin, Dirk Douwes-Schultz, Tahvi Frank, Falko Goettsch, Patrick Y Liu, Vishnu Nandakumar, Marissa B Reitsma, Vince Reuter, Nafis Sadat, Reed J D Sorensen, Vinay Srinivasan, Rachel L Updike, Hunter York, Alan D Lopez, Rafael Lozano, Stephen S Lim, Ali H Mokdad, Stein Emil Vollset, Christopher J L Murray

Summary

Background Understanding potential trajectories in health and drivers of health is crucial to guiding long-term investments and policy implementation. Past work on forecasting has provided an incomplete landscape of future health scenarios, highlighting a need for a more robust modelling platform from which policy options and potential

Published Online October 16, 2018 http://dx.doi.org/10.1016/

Fertility, mortality, migration, and population scenarios for 195 countries and territories from 2017 to 2100: a forecasting analysis for the Global Burden of Disease Study — **2020**

Stein Emil Vollset, Emily Goren, Chun-Wei Yuan, Jackie Cao, Amanda E Smith, Thomas Hsiao, Catherine Bisignano, Gulrez S Azhar, Emma Castro, Julian Chalek, Andrew J Dolgert, Tahvi Frank, Kai Fukutaki, Simon I Hay, Rafael Lozano, Ali H Mokdad, Vishnu Nandakumar, Maxwell Pierce, Martin Pletcher, Toshana Robalik, Krista M Steuben, Han Yong Wunrow, Bianca S Zlavog, Christopher J L Murray

Summary

Background Understanding potential patterns in future population levels is crucial for anticipating and planning for changing age structures, resource and health-care needs, and environmental and economic landscapes. Future fertility patterns are a key input to estimation of future population size, but they are surrounded by substantial uncertainty and diverging methodologies of estimation and forecasting, leading to important differences in global population projections. Changing population size and age structure might have profound economic, social, and geopolitical impacts in many countries. In this study, we developed novel methods for forecasting mortality, fertility, migration, and population. We also assessed potential economic and geopolitical effects of future demographic shifts.

Published Online July 14, 2020 https://doi.org/10.1016/S0140-6736(20)30677-2

See Online/Comment https://doi.org/10.1016/S0140-6736(20)31522-1 and S0140-6736(20)31523-3

Useful types of future health scenarios

- **Reference scenario (probabilistic forecast)** – what we would expect to happen in the future if:
  - The independent drivers of health continue to follow recent trends
  - The causal relationships between drivers and health outcomes stay the same
- The reference scenario is our estimate of the most likely future: it is simply a model-based forecast from past trends and past relationships between drivers and health outcomes predicted using future trends in drivers of health

- **Tailored scenarios** from alternative future trajectories for any combination of the independent drivers in the model

Drivers of health (SDI, risk factors, interventions) – All are forecasted

Sociodemographic index:	Occupational exposure to benzene	Short gestation for birth weight	Diet low in calcium	Number of motor vehicles per capita
Mean years of education	Occupational exposure to beryllium	Low birth weight for gestation	Diet low in seafood omega-3 fatty acids	Hypertensive heart disease/CKD
Income per capita	Occupational exposure to cadmium	Iron deficiency	Diet low in polyunsaturated fatty acids	Systolic blood pressure SEV
Total ferility under 25 years	Occupational exposure to chromium	Vitamin A deficiency	Diet high in trans fatty acids	Diabetes mellitus
Vaccines:	Occupational diesel engine exhaust	Zinc deficiency	Diet high in sodium	Fasting plasma glucose SEV
Measles (mcv1)	Occupational exposure to formaldehyde	Tobacco, alcohol, drug use:	Other behavioral risk factors:	Alcohol-related liver cirrhosis/CMP
Diphteria-tetanus-pertussis (dtp3)	Occupational exposure to nickel	Smoking	Intimate partner violence	Alcohol SEV
Hemophilus influenzae B (hib3)	Occup. polycyclic aromatic hydrocarbons	Chewing tobacco	Childhood sexual abuse	Preterm birth complication deaths
Pneumococcal conjugate (pcv3)	Occupational exposure to silica	Secondhand smoke	Bullying victimization	Low birth weight for gestation SEV
Rotavirus	Occupational exposure to sulfuric acid	Alcohol use	Unsafe sex	Protein energy malnutrition (PEM)
Water, sanitation, handwashing	Occupat. exposure to trichloroethylene	Drug use	Low physical activity	Child underweight SEV
Unsafe water source	Occupational asthmagens	Diet risk factors:	Metabolic risk factors:	Anemia
Unsafe sanitation	Occup. particulate matter, gases & fumes	Diet low in fruits	High fasting plasma glucose	Iron deficiency SEV
No access to handwashing facility	Occupational noise	Diet low in vegetables	High LDL cholesterol	Selcted pneumonia deaths
Air pollution, other environmental risks:	Occupational injuries	Diet low in legumes	High systolic blood pressure	Occupational exposure to silica SEV
Ambient particulate matter pollution	Occupational ergonomic factors	Diet low in whole grains	High body-mass index	HIV/AIDS drivers:
Household air pollution from solid fuels	Child and maternal malnutrition:	Diet low in nuts and seeds	Low bone mineral density	ART Price
Ambient ozone pollution	Non-exclusive breastfeeding	Diet low in milk	Impaired kidney function	Income per capita
Residential radon	Discontinued breastfeeding	Diet high in red meat	Cause-specific covariates	HIV-specific DAH/GHE
Lead exposure	Child underweight	Diet high in processed meat	Maternal (maternal HIV)	Child ART/cotrimoxazole coverage
Occupational exposure to asbestos	Child wasting	Diet high in sugar-sweetened beverages	Age specific fertility rate (+ HIV mortality)	PMTCT coverage
Occupational exposure to arsenic	Child stunting	Diet low in fiber	Road injuries	SEV = summary exposure value

From GBD 2019 non-optimal temperature (high and low temperature) is added as an environmental risk factor (Burkhart, Brauer, Aravkin et al. Lancet 2021)

Forecasting models

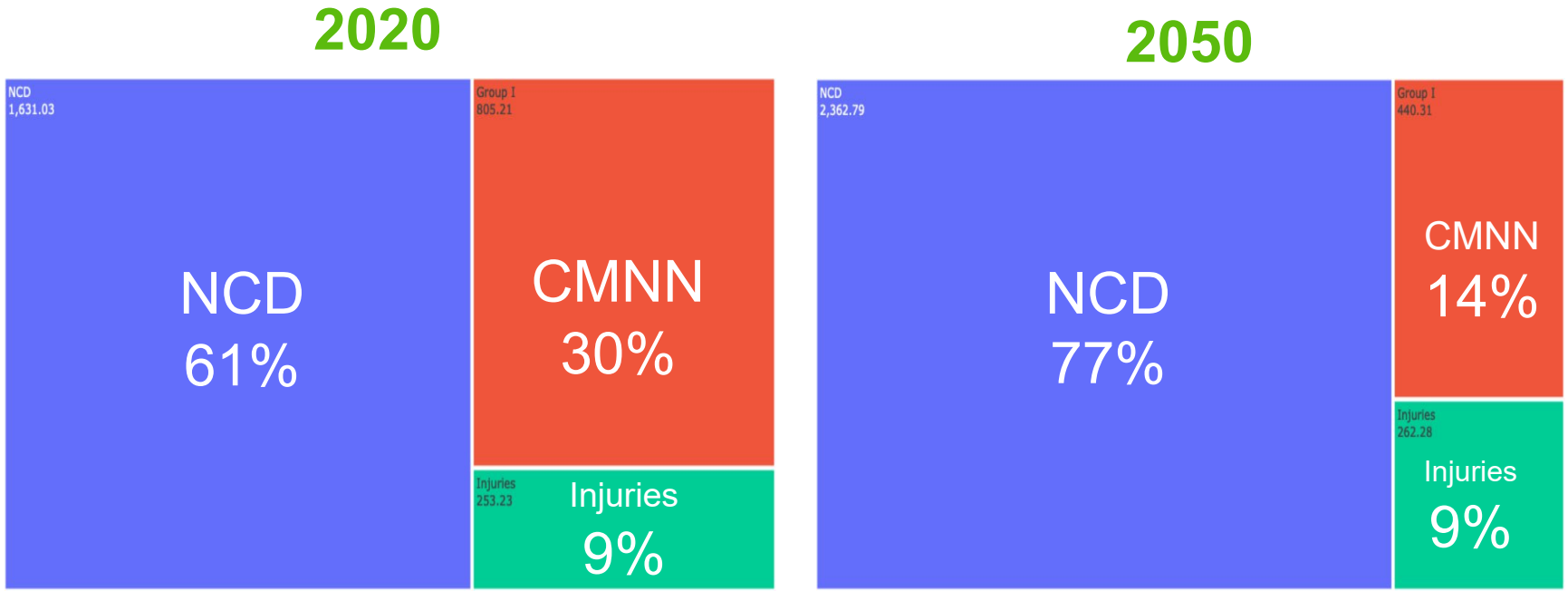
- **GBD mortality** is forecasted separately for males and females in cause-specific mixed-effects regression models with offset
  1. A risk factor scalar offset captures cause-specific combined risk factor effects based upon the GBD comparative risk assessment (quantification of risk-outcome associations accounting for risk factor mediation). 1
  2. The underlying (risk deleted) mortality is modelled as a function of SDI, time, and additional cause-specific covariates where appropriate 2
  3. Unexplained residual mortality (ARIMA on residuals) 3

Inputs needed: past cause-sex-specific mortality, past and future drivers of health (risk factors, vaccines, interventions, Sociodemographic Index, SDI, (GDP per capita, educational level, fertility under 25 years)

- **Prevalence and incidence** are modeled via mortality-to-incidence and mortality-to-prevalence and prevalence-only mixed-effects regression models with SDI as covariate

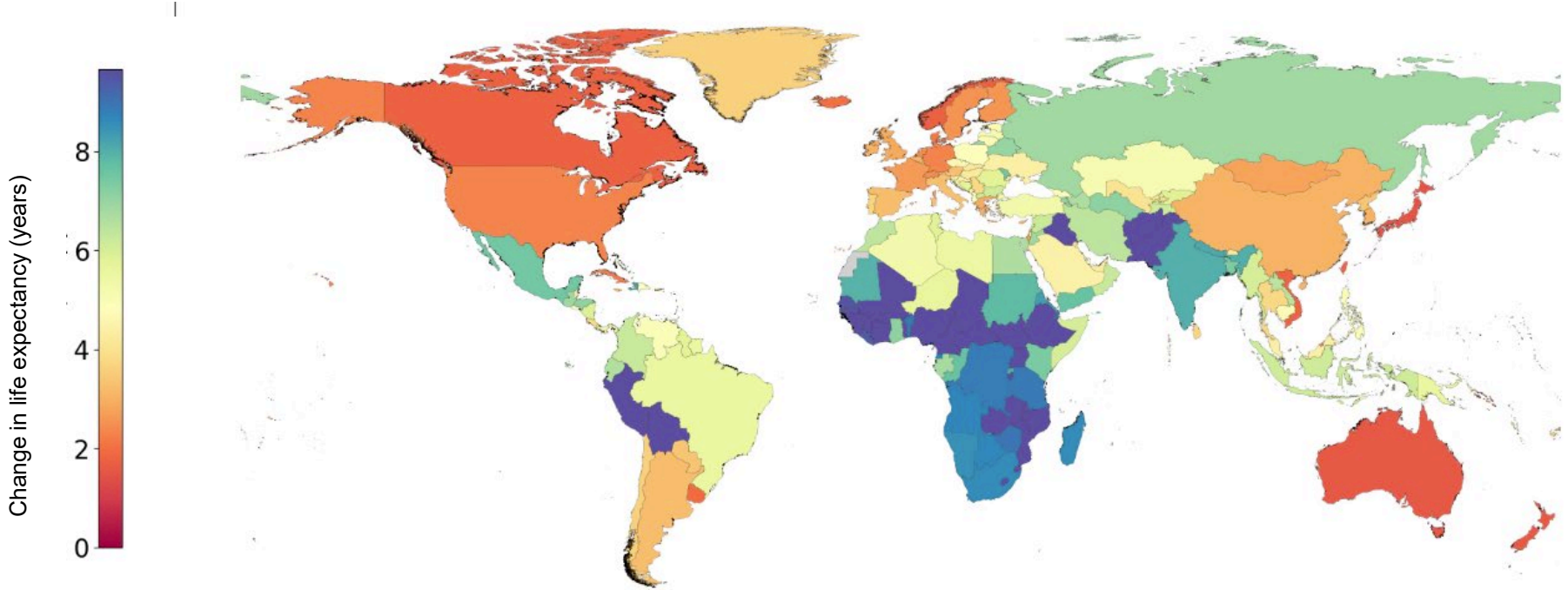
Selected results from ongoing work (all non-final)

Global shift in DALYs for level 1 causes from 2020-2050 - Counts (million)



NCD = non-communicable diseases; CMNN = Communicable, maternal, neonatal and nutritional diseases; Injuries (Transport, unintentional, self-harm and interpersonal violence)

Life expectancy – Change from 2020 to 2050 (reference scenario)

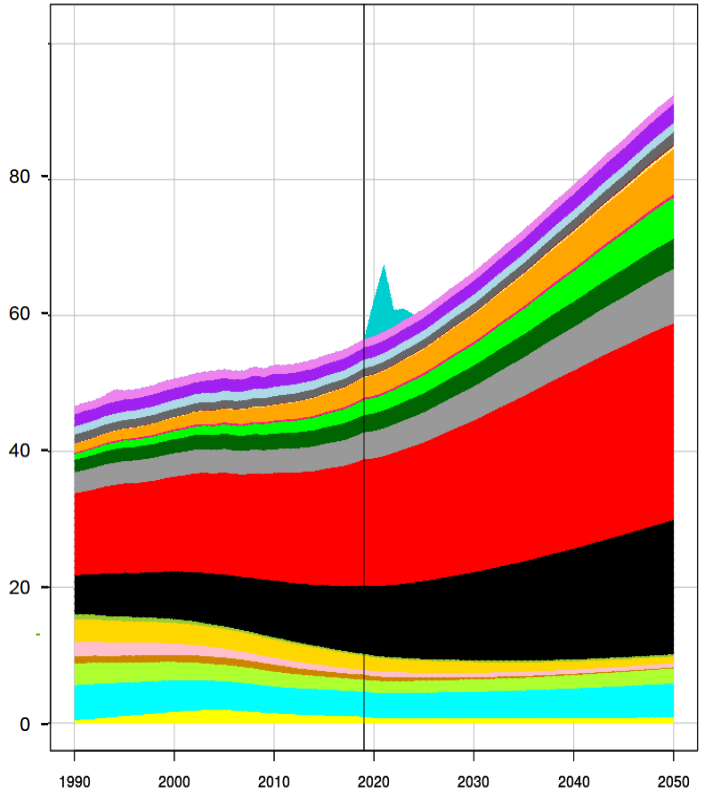


Global number of deaths (million) 1990-2050 – Level 2 / COVID-19

Total deaths (mill)
2019: 56.5
2020: 63.4
2021: 67.7
2022: 61.1
2023: 59.9

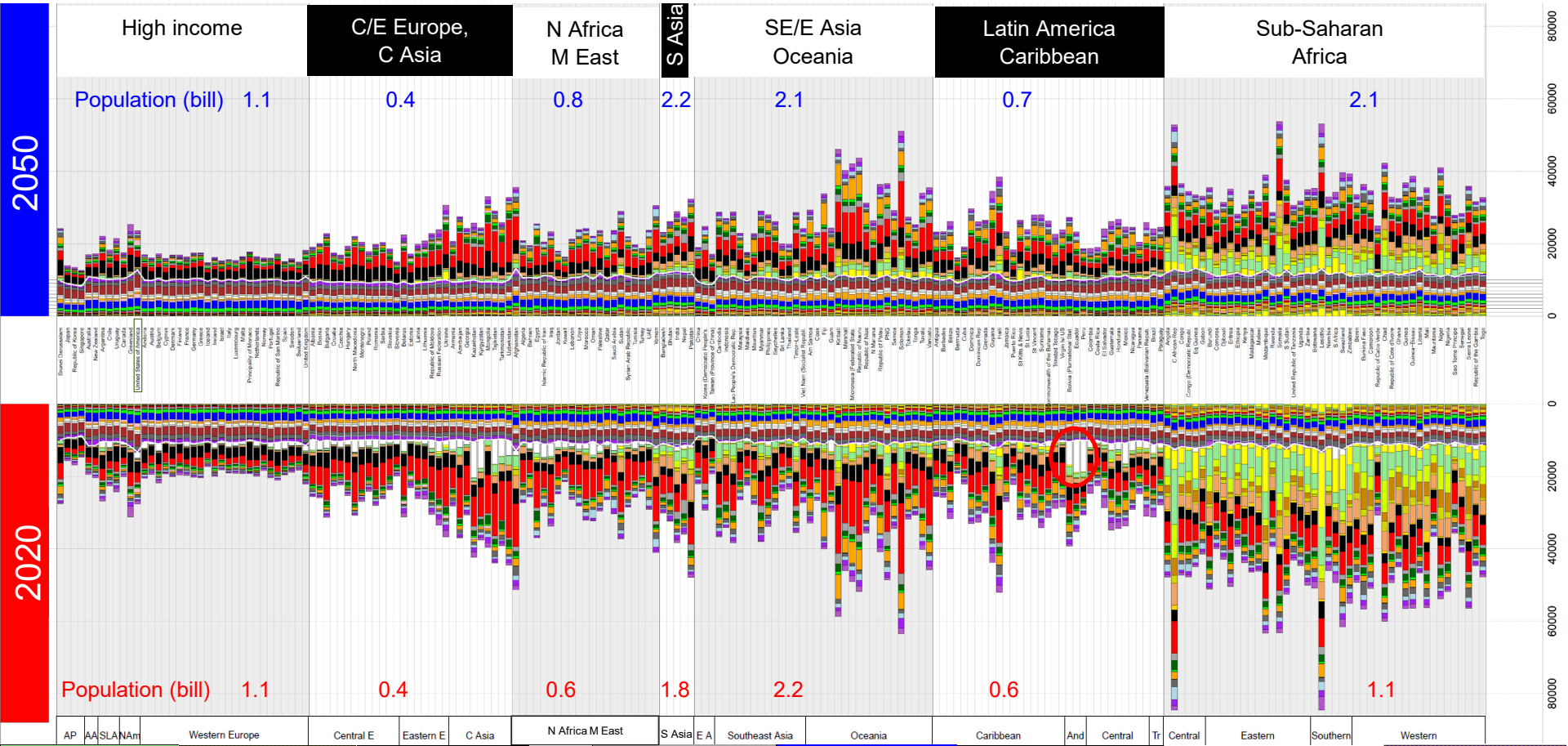
~ 7 mill 2020 excess mortality

~ 11 mill 2021 excess mortality



COVID−19
Self−harm and interpersonal violence
Unintentional injuries
Transport injuries
Other non−communicable diseases
Musculoskeletal disorders
Sense organ diseases
Skin and subcutaneous diseases
Diabetes and kidney diseases
Substance use disorders
Mental disorders
Neurological disorders
Digestive diseases
Chronic respiratory diseases
Cardiovascular diseases
Neoplasms
Nutritional deficiencies
Maternal and neonatal disorders
Other infectious diseases
Neglected tropical diseases and malaria
Enteric infections
Respiratory infections and tuberculosis (excl.COVID−19)
HIV/AIDS and sexually transmitted infections

All-in-one DALY plot (age-standardized rates): 2050 (top) versus 2020 (bottom)



Alternative scenarios - risk factor elimination by 2050*

Environmental risk factors

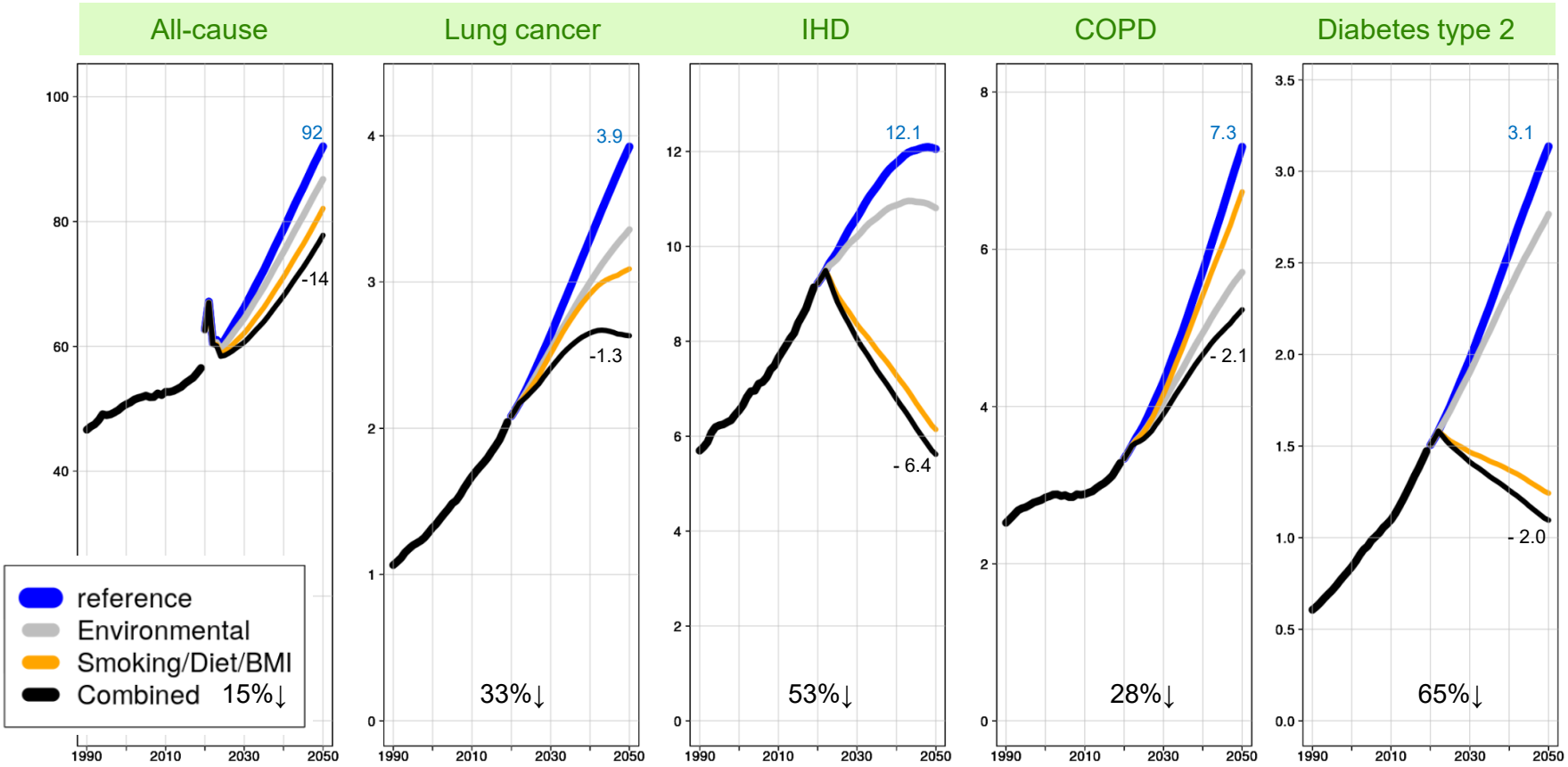
- Water
- Sanitation
- Hygiene
- Air Pollution
- Temperature

Behavioral risk factor

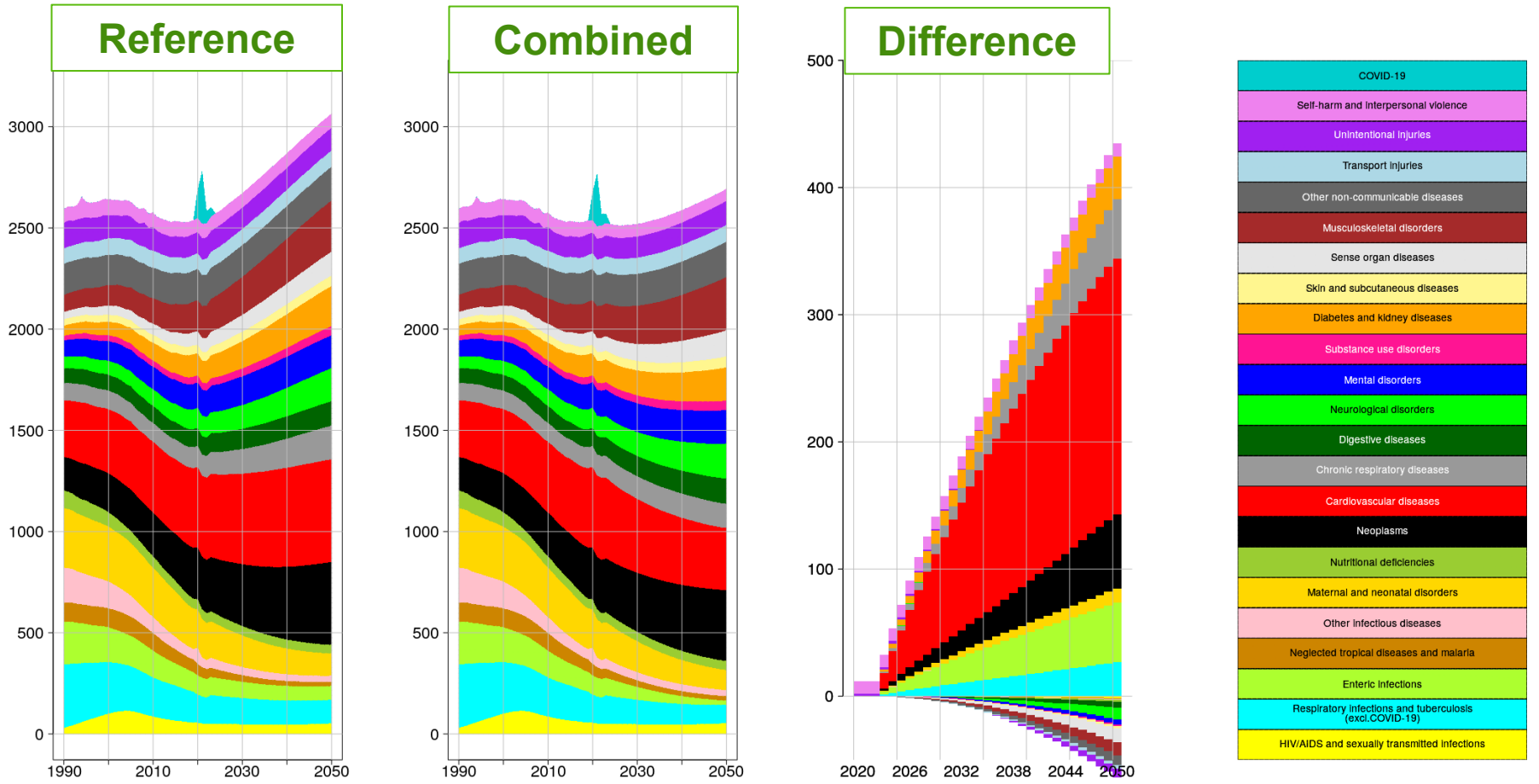
- Tobacco
- Diet
- BMI

*except temperature (two scenarios from Ou et al. Science 2021)

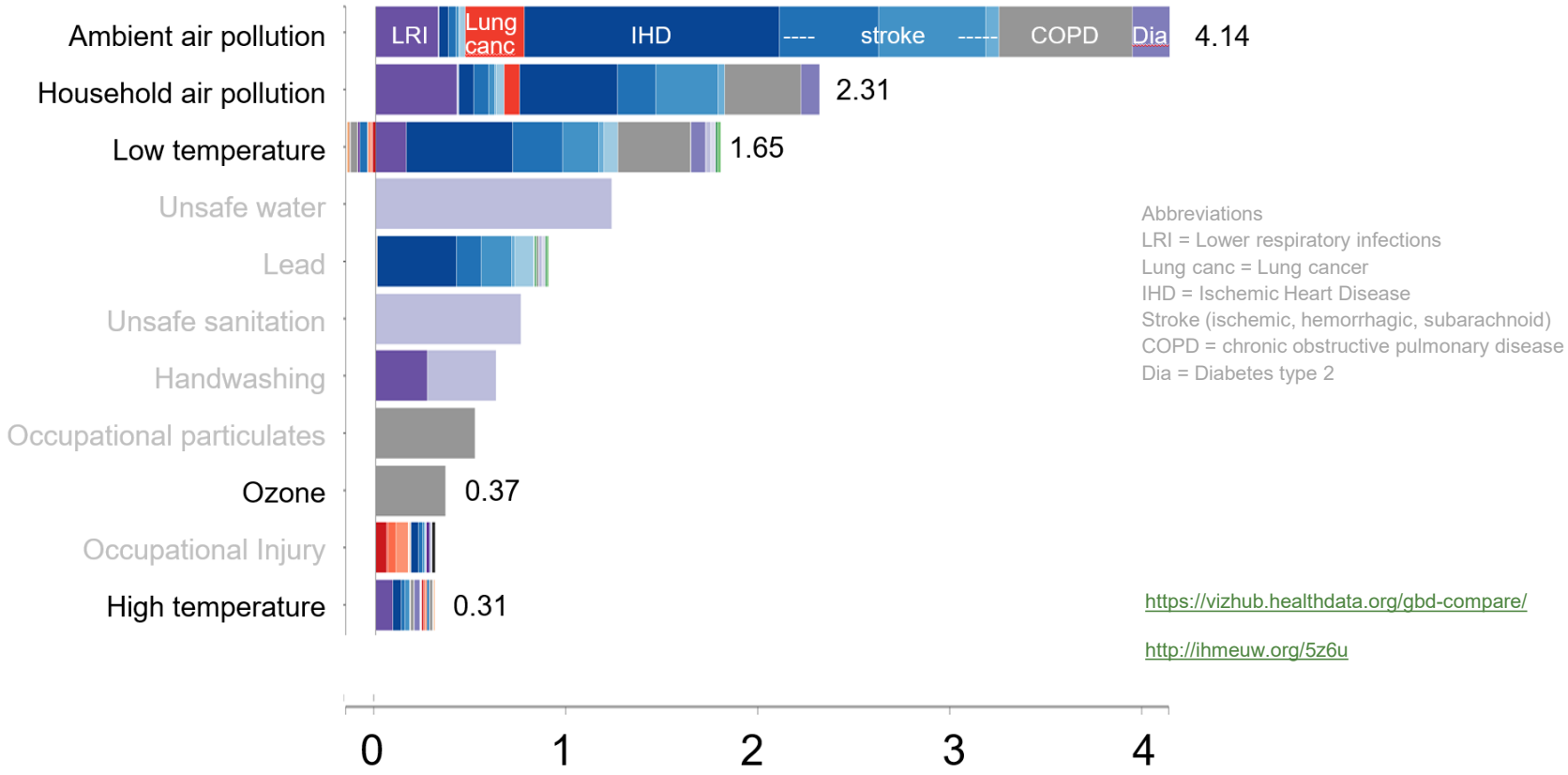
Global all-age deaths (million) by cause and scenarios



Global DALY counts (million) by level 2 causes and scenarios



Top global environmental risk factors GBD 2019



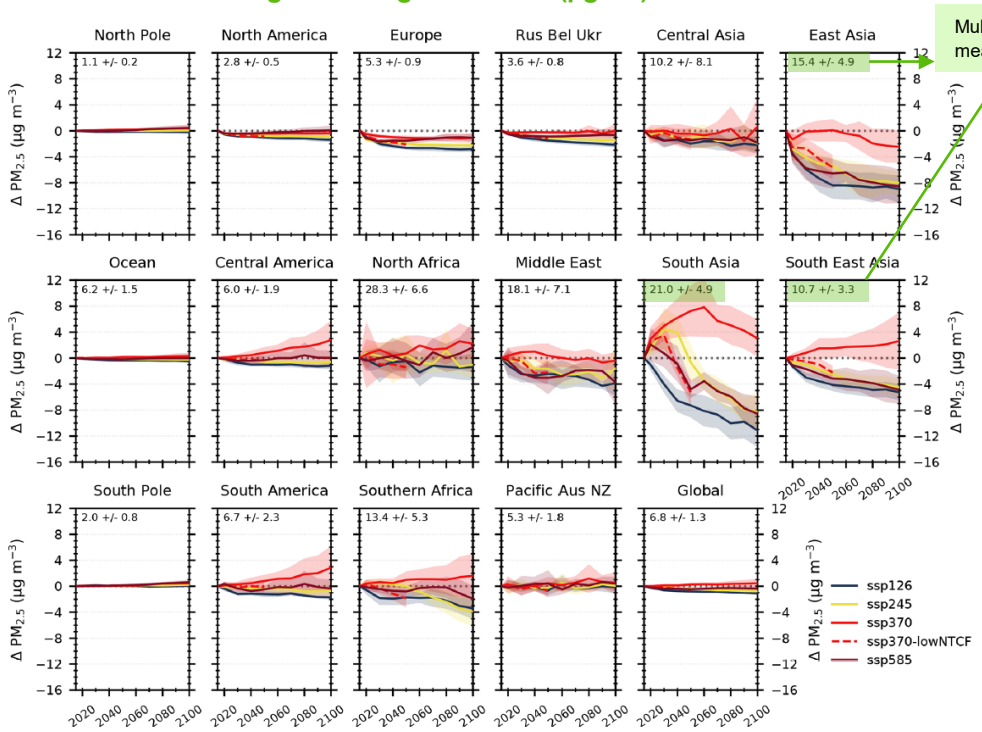
Abbreviations
LRI = Lower respiratory infections
Lung canc = Lung cancer
IHD = Ischemic Heart Disease
Stroke (ischemic, hemorrhagic, subarachnoid)
COPD = chronic obstructive pulmonary disease
Dia = Diabetes type 2

https://vizhub.healthdata.org/gbd-compare/

http://ihmeuw.org/5z6u

Work in progress: Estimate air pollution burden from CMIP6 models

2020 – 2100: PM2.5 change from regional mean (µg/m^3) for SSP-RCP combinations

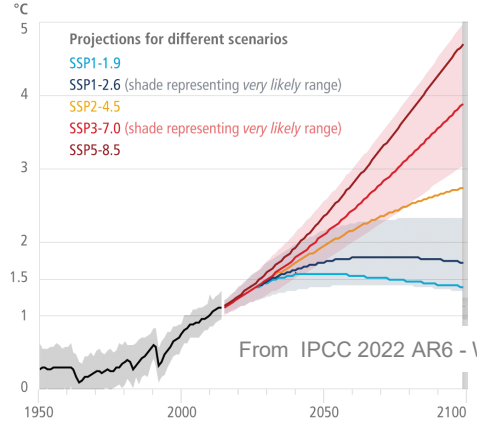


Multimodel regional mean (SD) PM2.5

SSP1 – RCP-1.9 (**1.5C**)
SSP1 – RCP-2.6 (**1.8C**)
SSP2 – RCP-4.5 (**2.7C**)
SSP3 – RCP-7.0 (**3.9C**)
SSP3 – RCP-7.0 – low NTCF
SSP5 – RCP-8.5 (**4.8C**)

SSP1 **Sustainability - Green road (strong apc*)**
SSP2 **Middle of the road (middle apc)**
SSP3 **Regional Rivalry - Rocky Road (weak apc)**
SSP4 **Inequality - Road Divided (weak apc)**
SSP5 **Fossil-fueled Development - Highway**

*apc = Air Pollution Control
SSPs = Shared Socioeconomic Pathways
NTCF = Near Term Climate Forcer (= SLCF)
CMIP6 = Coupled Model Intercomparison Project Phase 6



Global surface temperature change (relative to 1850-1900)

pessimistic

reference

optimistic

From IPCC 2022 AR6 - WGII

From: Turnock ST, Allen RJ, Andrews M, et al. Historical and future changes in air pollutants from CMIP6 models. Atmos Chem Phys 2020; 20:14547–79.

Summary - Forecasting the GBD

- We produce forecasts at full GBD granularity until 2050 (GBD measures, causes, risks, sex-age groups)
- Death, YLL, YLD, DALY, incidence, prevalence, 370 causes, 375 locations/204 countries, 23 age groups by sex, 1990-2050
- Population estimates to 2100 (includes all-cause mortality, fertility, migration)
- Forecasts are covariate driven using all risk factors in the GBD comparative risk assessment, SDI and selected interventions
- We produce tailored scenarios of risk factors and interventions (e.g., what happens if we set risk exposure from diet, BMI, air pollution, smoking, etc. to zero, or other trajectories of interest to policymakers or planners in health and other sectors)
- Work in progress: Estimate air pollution burden to 2100 for different climate scenarios