IHME
Measuring what matters

Future Health Scenarios – forecasting the GBD

Stein Emil Vollset, 29 June 2021

UNIVERSITY of WASHINGTON
Institute for Health Metrics and Evaluation

Overview of presentation

- Forecasting framework
  - Scenarios – scenarios based on risk factor trajectories – the role of mediation
  - Drivers of health
  - Mortality forecasting model
  - Non-fatal forecasts: incidence, prevalence, YLDs
- Cause-specific results to 2050 (preliminary GBD2019 based forecasts)

First GBD forecasts - Lancet 1997 and Science 1996

THE LANCET

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

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.

Methods We used the most important disease and injury trends since 1950 in nine cause-of-death clusters. 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, are highly uncertain, but we found some robust results with implications for health policy.

ganizations would provide the basic municipal grid information, the core of the effort. Information volunteers and public safety agencies would update the system once a disaster strikes.

Unlike the 911 system, the 711 system would not be a one-way, top-down communications system, but rather a genuine interactive and horizontal communications medium connecting affected citizens, their loved ones, and rescue efforts. The technology is available and affordable; the user base is strong and growing; and the time is here and now.

Evidence-Based Health Policy—Lessons from the Global Burden of Disease Study

Christopher J. L. Murray and Alan D. Lopez

It is both extraordinary and unfortunate that at the end of the 20th century, the international public health community does not routinely quantify or project the health problems of populations. There are no standardized compilations of comparable information on the extent of morbidity, disability, or death in different populations of the world. Information at a global or regional level on behaviors and exposures that are important risk factors for death and disability is also extremely limited. Although the demographic community routinely publishes projections of fertility and population, future trends have been projected for only a very limited number of causes of death [such as the human immunodeficiency virus (HIV)] in selected populations.

All too often, health statistics are provided by "advocacy officers." Public health policy formulation desperately needs independent, objective information on the magnitude of health problems and their likely trends, based on standard units of measurement and comparable methods. (In this case, we are defining health problems broadly to include diseases, injuries, and exposures to important risk factors.)

The Global Burden of Disease Study

A major effort to foster an independent, evidence-based approach to public health policy formulation is the Global Burden of Disease Study (GBD). This study was initiated in 1992 at the request of the World Bank; over the past 4.5 years, the work has been undertaken with the full collaboration

certified causes of death are available, a series of analyses has been undertaken to adjust for miscoding of cardiovascular, injury, and other deaths. In some cases, these corrections for miscoding substantially alter the estimated death rates (for example, after correcting for coding of cardiovascular deaths in Japan that had been assigned to various ill-defined categories, the death rate from ischemic heart disease increased by a factor of 2.8). To ascertain the causes of death for the remaining 70 percent of deaths in the world, a variety of methods and sources has been used, including sample registration systems in China and rural India; small population laboratory studies in sub-Saharan Africa and Asia; estimates based on epidemiologic studies of the incidence, prevalence, and case-fatality rates of particular diseases; and, as a last resort, models relating cause-specific mortality for an age-sex group to mortality from all causes in that age group.

For each disease and its sequelae, epidemiological estimates based on a metasynthesis of published and unpublished studies have been developed. For example, estimates of incidence, prevalence, and duration for five sequelae of diabetes were developed: diabetes itself, retinopathy, neuropathy, amputation, and diabetic foot. Internally consistent estimates of incidence, prevalence, case-fatality, remission, and mortality rates and of duration were developed with the aid of computer models (5).

To foster comparisons across conditions and risk factors, a composite measure of the burden of each health problem has been developed: the Disability-Adjusted Life Year (DALY) (6). DALYs from a condition

Mortality forecasting paper Lancet 2018

Published **Online**
October 16, 2018

Global Health Metrics

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

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

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OPEN ACCESS

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 health trajectories can be assessed. This study provides a novel approach to modelling life expectancy, all-cause mortality and cause of death forecasts —and alternative future scenarios—for 250 causes of death from 2016 to 2040 in 195 countries and territories.

Published **Online**
October 16, 2018
http://dx.doi.org/10.1016/S0140-6736(18)31694-5

See **Online/Comment**
http://dx.doi.org/10.1016/S0140-6736(18)31861-0

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FORTUNE

LIFE EXPECTANCY

People in China Will Soon Outlive Americans, But the Spanish Will Outlive Us All

The Guardian 17 Oct 2018


Mediterranean diet to put Spain top of table for life expectancy by 2040

Sarah Boseley
Health editor

Population forecasting paper Lancet 2020

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

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.

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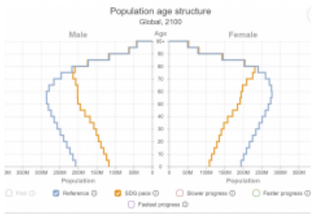
https://doi.org/10.1016/S0140-6736(20)30677-2
See Online/Comment
https://doi.org/10.1016/S0140-6736(20)31522-1 and S0140-6736(20)31523-3

healthdata.org: Visualization tool available at time of publication



JULY 14, 2020

Population Forecasting

Data Visualization

Learn more

Use this dynamic tool to explore patterns in population trends from 2017 to 2100. The interactive tool reveals changes in population structures and fertility rate, based on progress toward SDG pace of female educational attainment and access to contraception.

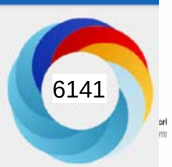
The Guardian

World population in 2100 could be 2 billion below UN forecasts, study suggests

The New York Times

World Population Could Peak Decades Ahead of U.N. Forecast, Study Asserts

The study, published in The Lancet, said an accelerated decline in fertility rates means the global population could peak in 2064 at 9.7 billion and fall to 8.8 billion by century's end.



CNN

World's population likely to shrink after 50 years

By Amy Woodyatt, CNN

Updated 2259 GMT (0659 HKT) July 14, 2020

HuffPost

CRONACA 15/07/2020 07:43 CEST

Studio Lancet: "Nel 2100 due miliardi di persone in meno di stime Onu. Italia dimezzata"

Considerati il calo dei tassi di fertilità e i tassi di invecchiamento. La Terra ospiterà 8,8 miliardi di persone

Bloomberg

World

World Population Likely to Begin Falling After 2050, Study Says

By Jade Wilson

July 14, 2020

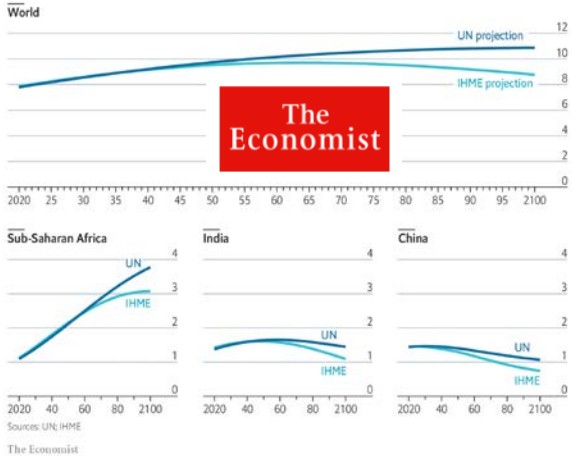
Le Monde

JEUDI 16 JUILLET 2020

La population pourrait décroître avant 2100

Des universitaires américains suggèrent qu'un pic démographique sera atteint en 2064

The Economist



The Japan Times

WORLD

World population in 2100 could be 2 billion below U.N. projections, study shows

Useful types of future health scenarios

- **Reference scenario** – what we would expect to occur in the future if:
  - The independent drivers of health continue to follow recent trends
  - The causal relationships between independent drivers and health stay the same
- The reference scenario is not a prediction of what will happen - it is simply what would happen based on forecasting past trends in drivers of health and past relationships between drivers and outcomes

- **Better (85)** and **worse (15) scenarios** – rates of change for each independent driver is set to the 85th and 15th percentiles, respectively, of observed rates of change across locations and years in the past
- **Tailored scenarios** from of alternative future trajectories for any combination of the independent drivers in the model

Custom scenarios: examples from past analyses

- **Population scenarios**
  - Different trajectories of female education and met need for modern contraceptives; all other drivers at reference
- **Diet scenarios**
  - Adjust all diet SEVs to 0 by 2030 (assuming an “optimal” diet); all other drivers at reference
- **Paris climate agreement scenarios**
  - Adjust carbon emissions for all countries to their Paris Climate Agreement goals in 2030; all other drivers at reference

Heart of the forecasting method is independent drivers of health

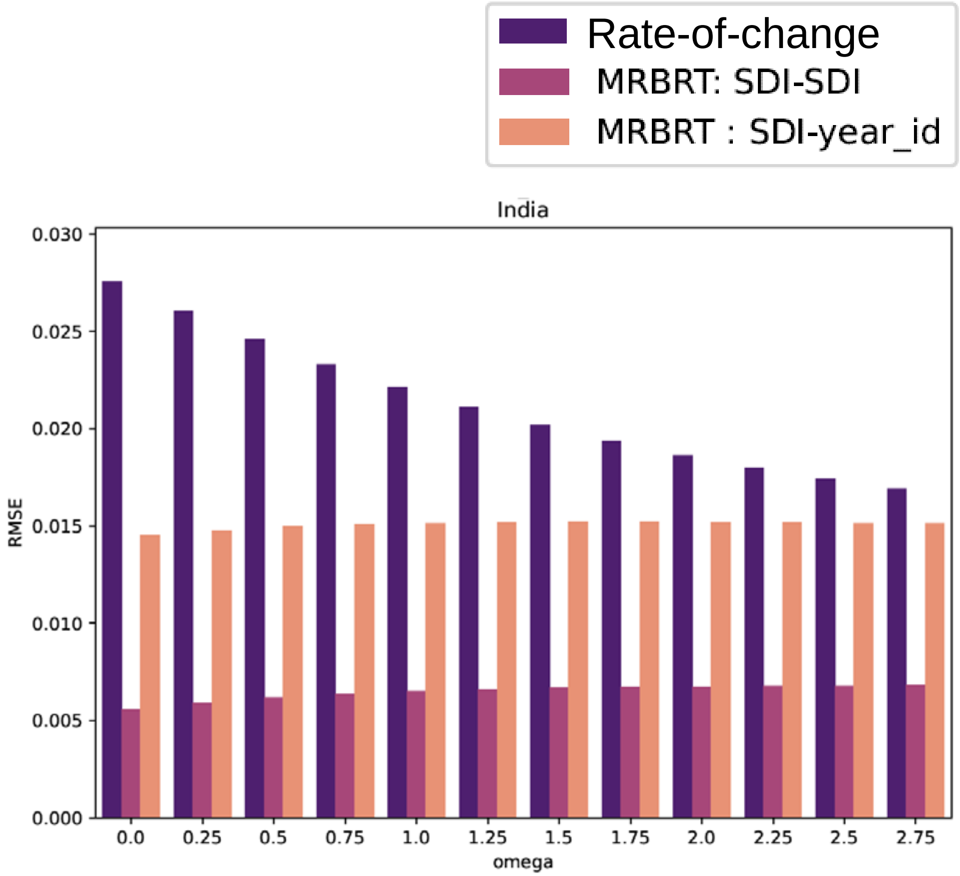
- Forecasted independent drivers are input to the mortality forecasting model
- Two categories of independent drivers
- Socio-demographic drivers include GDP per capita, educational attainment and the total fertility rate under 25 years (TFU25); combined in the forecasting model to the GBD sociodemographic index (SDI)
- Risk factors and interventions – all 79 GBD risk factors and a short-list of interventions are included as independent drivers (5 vaccines and drivers of HIV/AIDS incidence and mortality (ART coverage etc))

Drivers of health – 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

Forecasting risk exposure – modeling updates

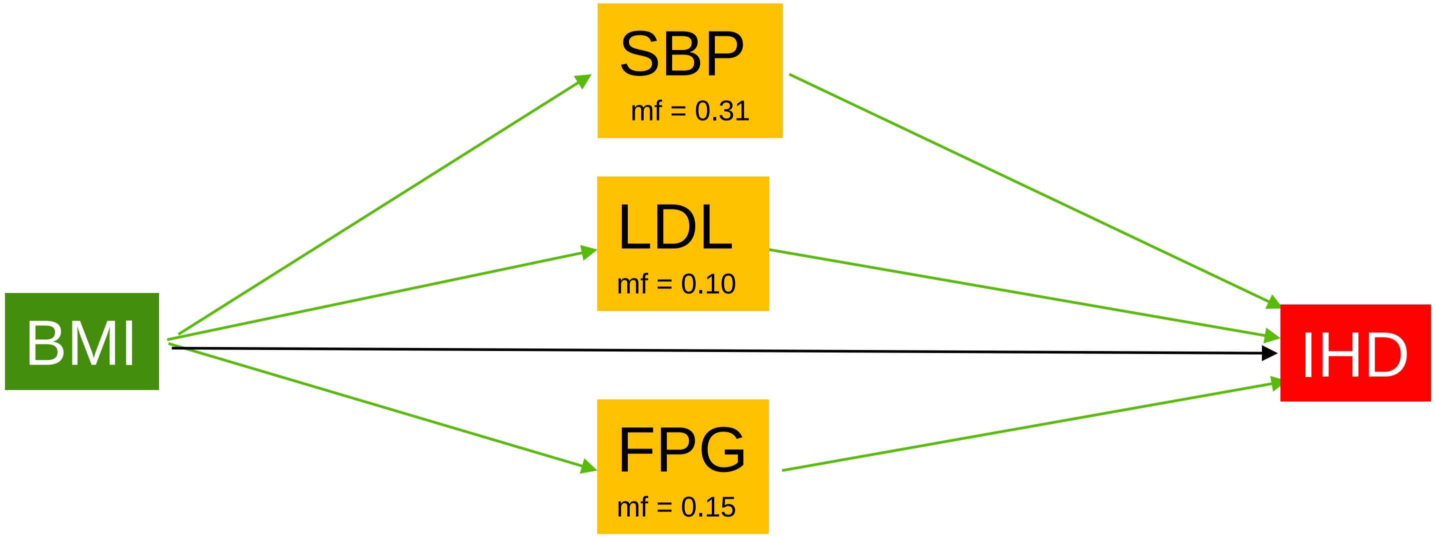
- Previously modeled risk exposure based solely on past time trends
- New MRBRT* models have been developed using the sociodemographic index (SDI) as a driver of risk exposure
- In order to stabilize our modeling approach across risks and locations, we have developed an ensemble approach: 3 different models with 12 settings of recency weighs on past years
- Ensemble model uses predictive validity to rank and weight models according to the best fit for each location and each risk factor



*MRBRT = IHME’s Bayesian meta-regression tool

Risk factor mediation

- A risk factor may exert its effect on a disease through one or more mediator risks Example: high body mass index (BMI) and ischemic heart disease (IHD) with mediation through 3 risk factors. Mediation factor (mf) is the proportion of excess risk mediated through each mediator risk factor. Also note the unmediated (direct) effect from BMI to IHD



$RR^{M} = (RR - 1)mf + 1$

$RR^{U} = (RR - 1)(1 - mf) + 1$

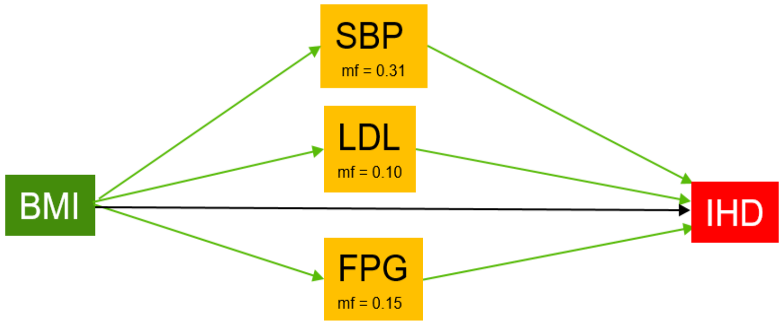
LDL= low density lipoprotein (LDL), SBP= systolic blood pressure, FPG= fasting plasma glucose

Mediation matrix

- Mediation matrix of GBD 2019 consists of 135 risk-mediator-cause entries involving 26 causes and 28 risk factor, of which 11 are mediators (see below)
- The main motivation for accounting for mediation and use of mediation matrix has been to avoid double counting when calculating disease burden attributable to clusters of risk factors (eg all risk factors combined, or all diet risks combined)
- Novel use of mediation to forecast future burden for policy relevant scenarios constructed from future risk factor trajectories

Entries of mediation matrix from BMI – IHD example

Distal risk		**mediator cause**	**mf**
metab_bmi_adult	metab_sbp	cvd_ihd	0.312
metab_bmi_adult	metab_ldl	cvd_ihd	0.100
metab_bmi_adult	metab_fpg	cvd_ihd	0.149

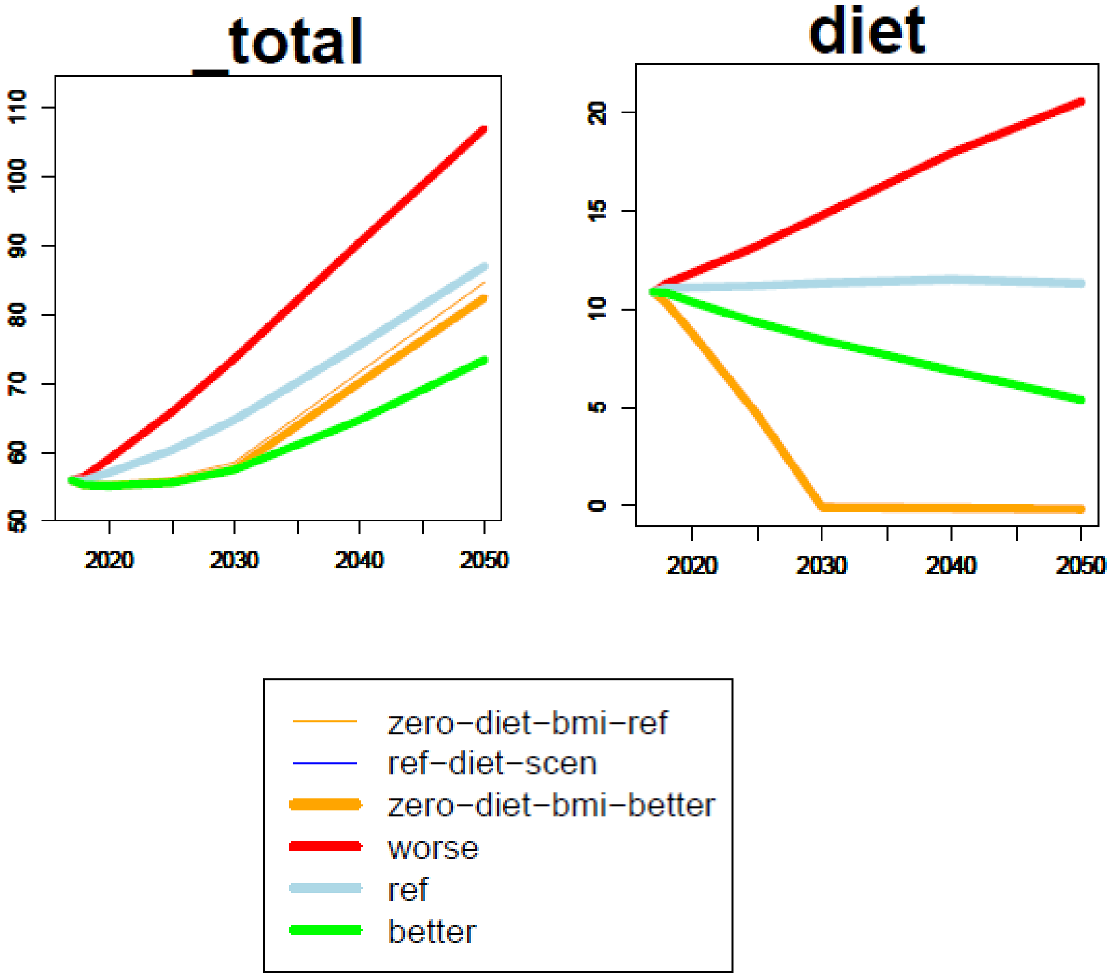


To support development of policy relevant scenarios several improvements in the forecasting approach are ongoing

1) Reviewed and revised the causal web linking distal behavioral and environmental risks to risk mediators such as systolic blood pressure (SBP) – known in the GBD lexicon as the mediation matrix.
2) Development of the concept of the intrinsic level of mediator risks – the level of a mediator such as systolic blood pressure or fasting plasma glucose (FPG) not explained by the trends in distal risk factors that flow through the mediator.
3) Ensemble model for forecasting distal risks and intrinsic levels of mediators.

Rockefeller Foundation project on diet

- In 2019, we conducted a modeling exercise to forecast the longer term impact of shifting over a decade to the GBD optimal diet on health outcomes.
- In 2050, our forecasting framework suggested that attributable deaths to poor diet would be 11 million deaths.
- Switching to an optimal diet over that time period, avoided only 4 million deaths in 2050.
- Unpacking this problem revealed the key issue was the trend in the mediators (SBP, FPG, LDL) linked to the trend in the distals.

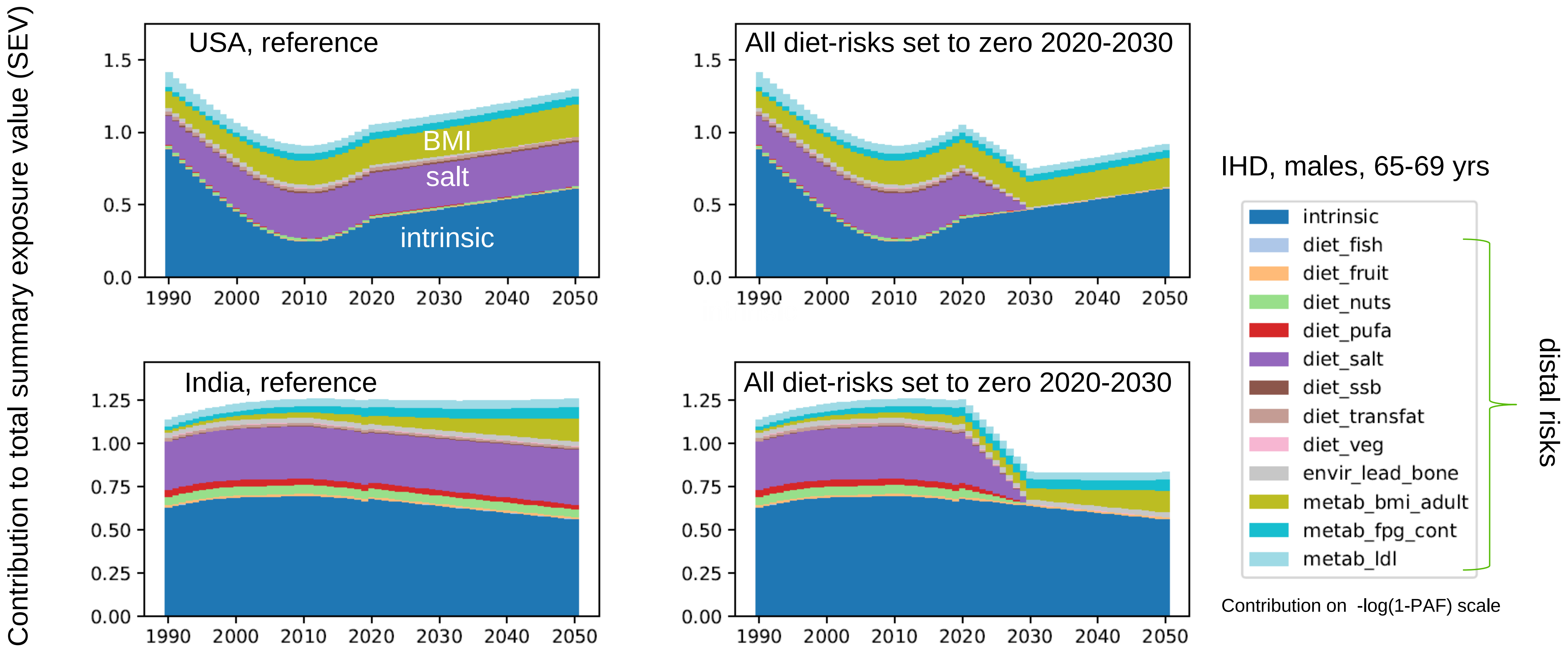


Revisions of forecasting approach and GBD

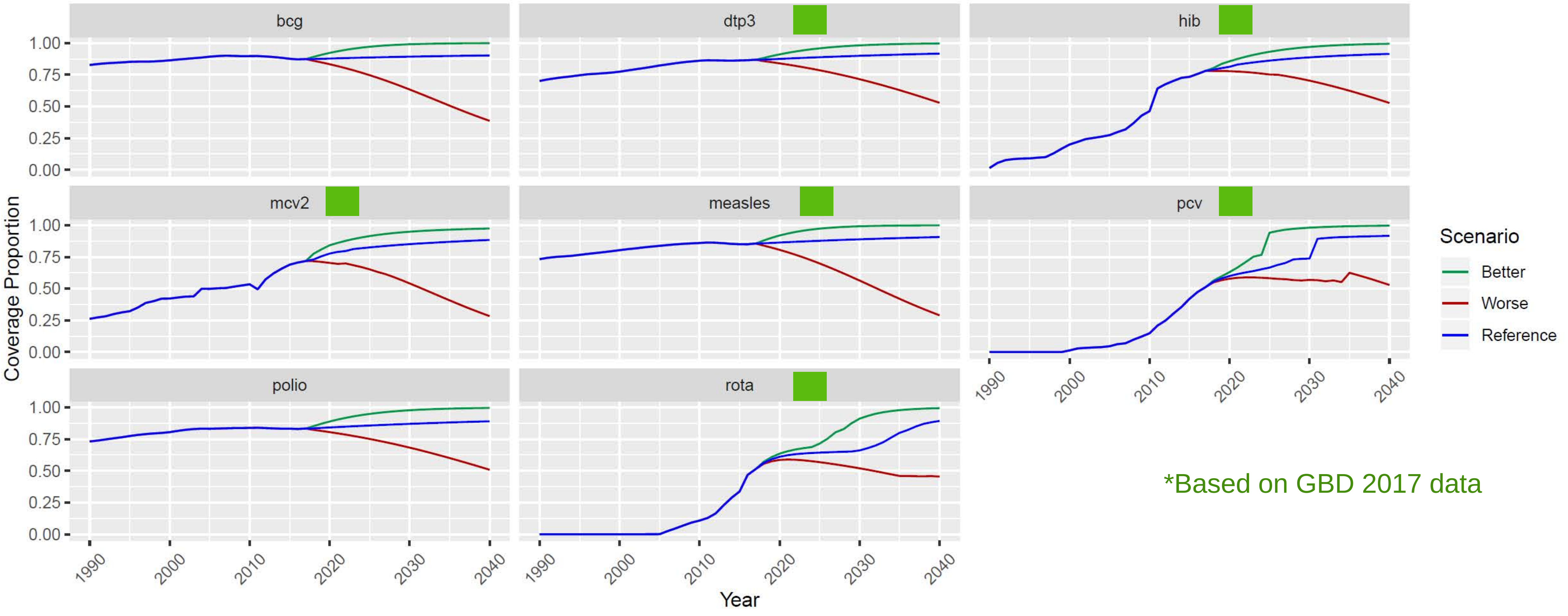
- To solve the 11 million attributable diet deaths versus the 4 million avoided diet deaths problem has led to three major revisions:

  - Modeling the trajectory of risk factors that are mediators as a function of distal risks and unexplained trends in the mediator called the intrinsic summary exposure value (intrinsic SEV). The level of a mediator such as systolic blood pressure or fasting plasma glucose (FPG) not explained by the trends in distal risk factors that flow through the mediator.
  - Much greater scrutiny on the evidence for mediation pathways and the mediation factors including identifying implied missing outcomes for many distal risks.
  - Using the evidence score to help guide the choice of new risk-mediator-outcome pathways to add to the GBD and FHS.

Contribution of intrinsic to total SEV for blood pressure for USA and India



Example interventions: Global forecasts of Vaccine Coverage



*Based on GBD 2017 data

Modeling future mortality - 3 components

- We forecast cause-specific mortality as follows (200+ causes sex-specific):

1. Remove effect of risk factors and interventions - gives us risk-deleted or underlying cause-specific mortality (scalars in model = multipliers of mortality rate) 1
2. Model cause-sex-specific underlying mortality with Sociodemographic index (SDI) and time as explanatory variables (mixed effects linear model with priors; age-location & age-time random effects) 2
3. What is not explained with risk factors/interventions and SDI/time is modelled with time-series (ARIMA) models 3

Input needed: past cause-specific mortality, past and future drivers of mortality (risk factors, vaccines, SDI (GDP per capita, educational level, fertility under 25 years)

Mortality forecasting model

6.1.1 All causes except HIV, disasters, war and terrorism, legal interventions

The cause-specific model, used for 270 of 274 causes and cause groups, is composed of three components:

1. The underlying (or risk deleted) mortality, modelled as a function of the SDI[3], time, and additional cause-specific covariates where appropriate.
2. A risk factor scalar that captures cause-specific combined risk factor effects based upon the GBD comparative risk assessment, which quantifies risk-outcome associations accounting for risk factor mediation.[5]
3. Unexplained residual mortality.

Specifically, the total mortality rate m^T_{ilast} for cause i, location l, age group a, and sex s at time t was decomposed in log space into an underlying mortality rate m^U_{ilast}, a risk factor scalar* $\mathbb{S}_{ilast}$, and residual ϵ_{ilast} as

$$\ln(m^T_{ilast}) = \underbrace{\alpha_{ilas} + \beta_{is}\mathrm{SDI}_{lt} + \theta_{ias}t}_{\ln(m^U_{ilast})} + \ln(\mathbb{S}_{ilast}) + \epsilon_{ilast}$$

Separate models by cause and sex

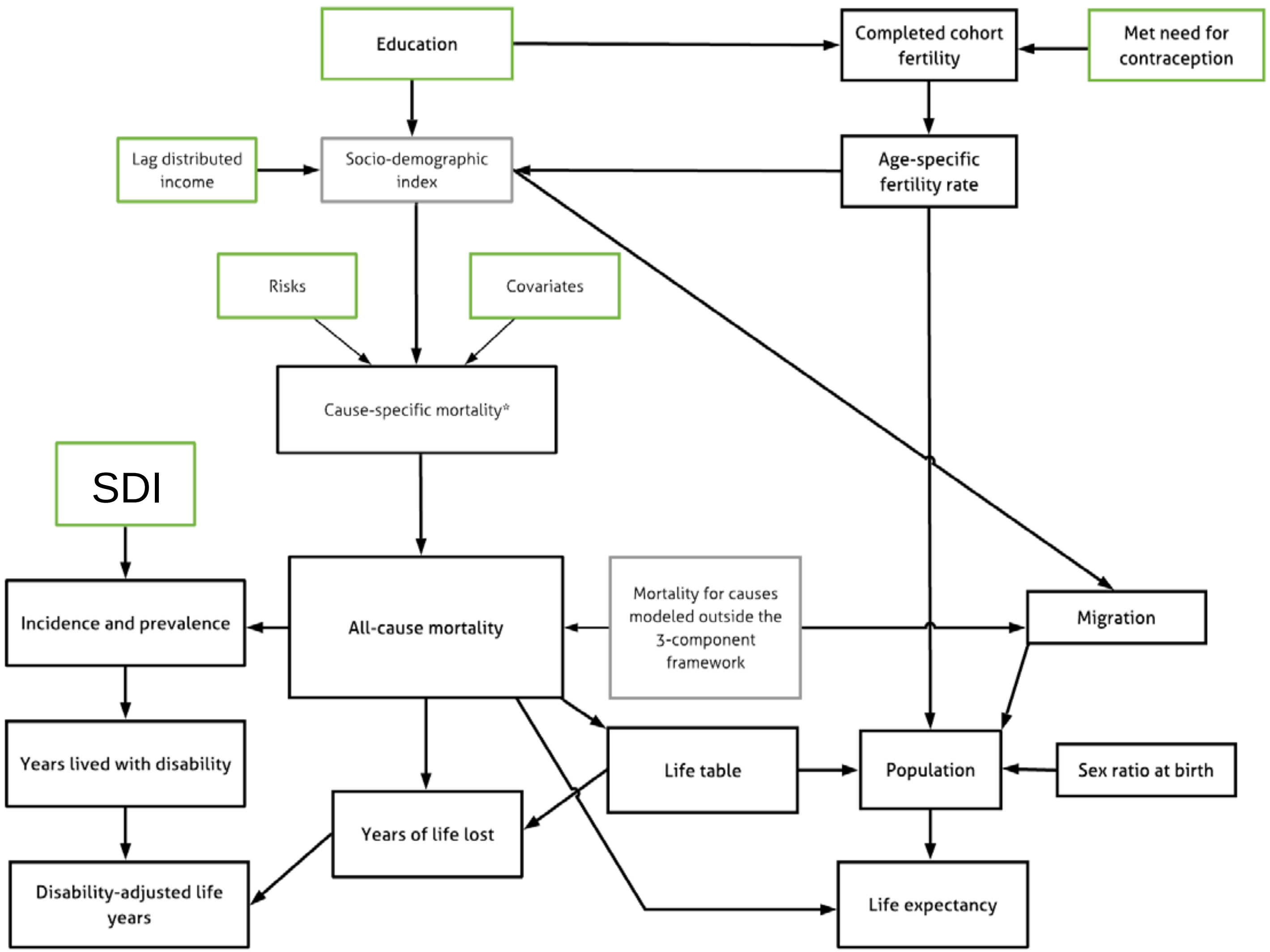
where for the ith cause and sth sex , $\alpha_{ilas} \sim \mathrm{N}(\beta_{\alpha,is}, \tau^2_{\alpha,is})$ is a location-age-specific random intercept, β_{is} is a global fixed slope on SDI, and $\theta_{ias} \sim \mathrm{N}(\beta_{\theta,is}, \tau^2_{\theta,is})$ is an age-specific random slope on the secular time trend. This model

* Note the risk factor scalar ($\mathbb{S}$) is computed from the combined population attributable fraction (PAF) of all GBD risks causally related to each modelled cause; scalar = 1/(1-PAF); the scalar represents the ratio of the total to the underlying or risk-deleted cause-specific mortality)

From Appendix Vollset et al. Lancet 2020

Overview

systematic
multistage
complex
interdependent



Non-fatal models – brief overview

- Incidence and prevalence are modelled from mortality via mortality/incidence (MI) and mortality/prevalence(MP) ratios with SDI as covariate
- For non-fatal only causes we model prevalence directly

$$log(R_{a,s,l,y}) = \beta_0 + \beta_1 SDI_{l,y} + \pi_{0:a,s,l} + \pi_{1:a,s,l} SDI_{c,y} + \epsilon_{a,s,l,y} \qquad (1)$$

Where $R_{a,s,l,y}$ is the age-sex-location-year specific ratio of a given cause (i.e. mortality/prevalence, mortality/incidence, prevalence/incidence, or YLD/YLL), with the covariate $SDI_{l,y}$ being the location-year specific SDI. $\pi_{0:a,s,l}$ is the age-sex-location specific random intercept, $\pi_{1:a,s,l}$ is the age-sex-location specific slope on SDI, and $\epsilon_{a,s,l,y}$ is the noise component. SDI is the geometric mean of three scaled components: fertility under 25 years, educational attainment per capita, and lag-distributed income per capita. A shift in log space is applied to each age-sex-location combination after prediction in order to align the value of the last known past year with the modeled value in that year.

Prevalence:

$$logit(P_{a,s,l,y}) = \beta_0 + \beta_1 SDI_{l,y} + \pi_{a,s,l} + \epsilon_{a,s,l,y} \qquad (2)$$

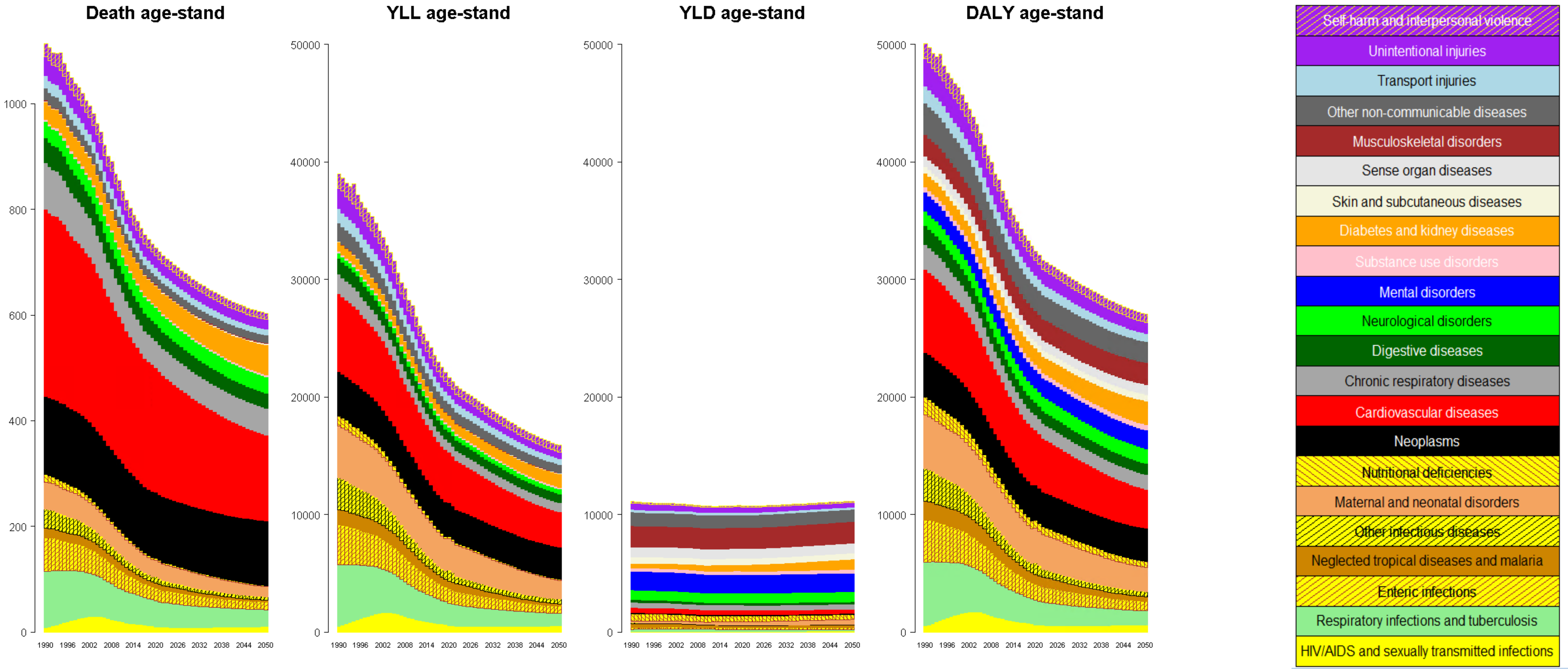
Where $P_{a,s,l,y}$ is the age-sex-location-year specific prevalence of a given cause, with the covariate $SDI_{l,y}$ being the location-year specific SDI. $\pi_{a,s,l}$ is the age-sex-location specific random intercept, and $\epsilon_{a,s,l,y}$ is the noise component.

Forecasting granularity

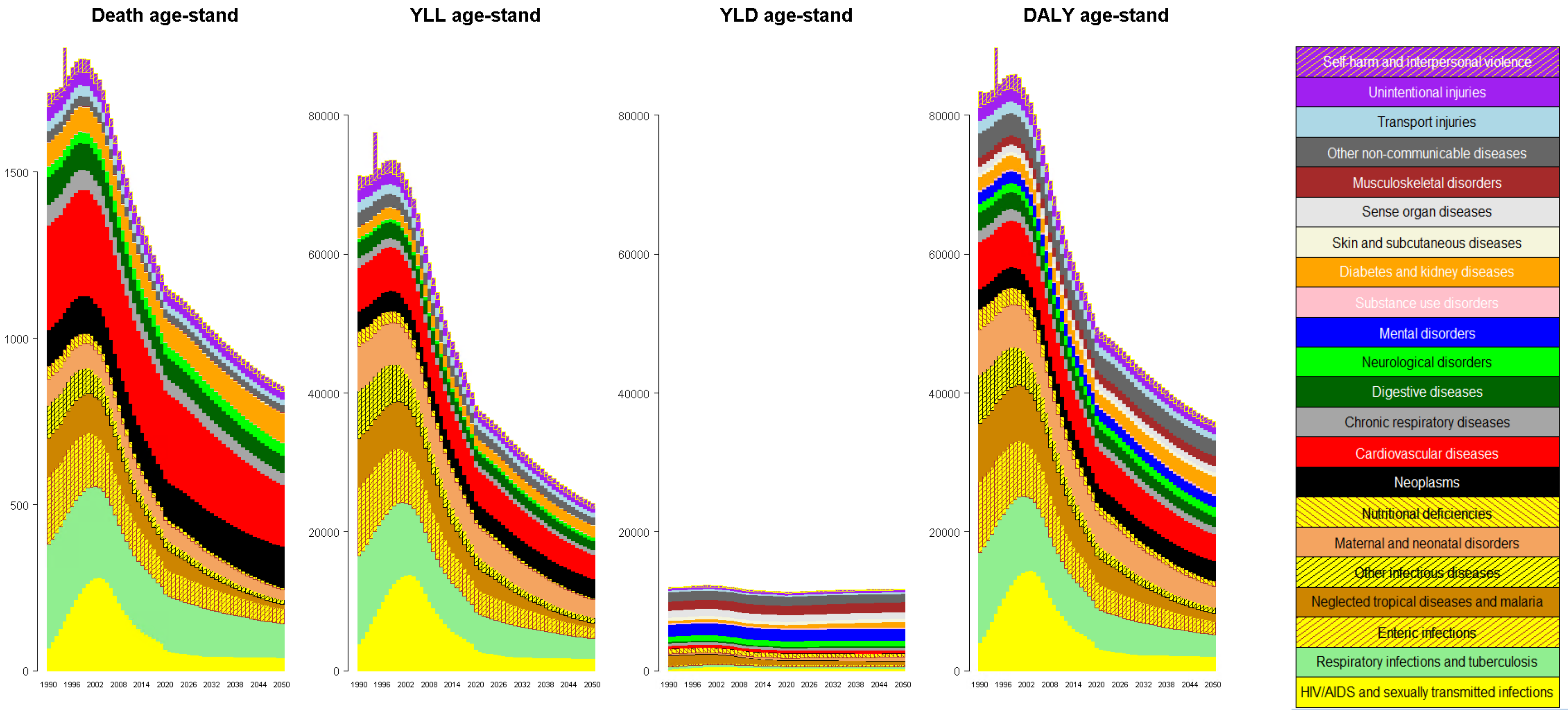
- The Future Health Scenarios mission is to forecast each round of the GBD
- We forecast all the 369 GBD 2019 causes and cause aggregates with only a few exceptions
- 23 age groups, males and females, and 204 country locations
- Subnational estimation for China, India, United States and Brazil
- Cause specific results from 2020 – 2050
- All GBD main measures: deaths, YLLs, YLDs, DALYs, incidence, prevalence, life expectancy, HALE
- 2100 populations (including all-cause mortality, fertility, migration)
- Future comparative risk assessment (CRA) for all GBD risk factors; avoidable burden

GBD 2019 based burden forecasts (preliminary)

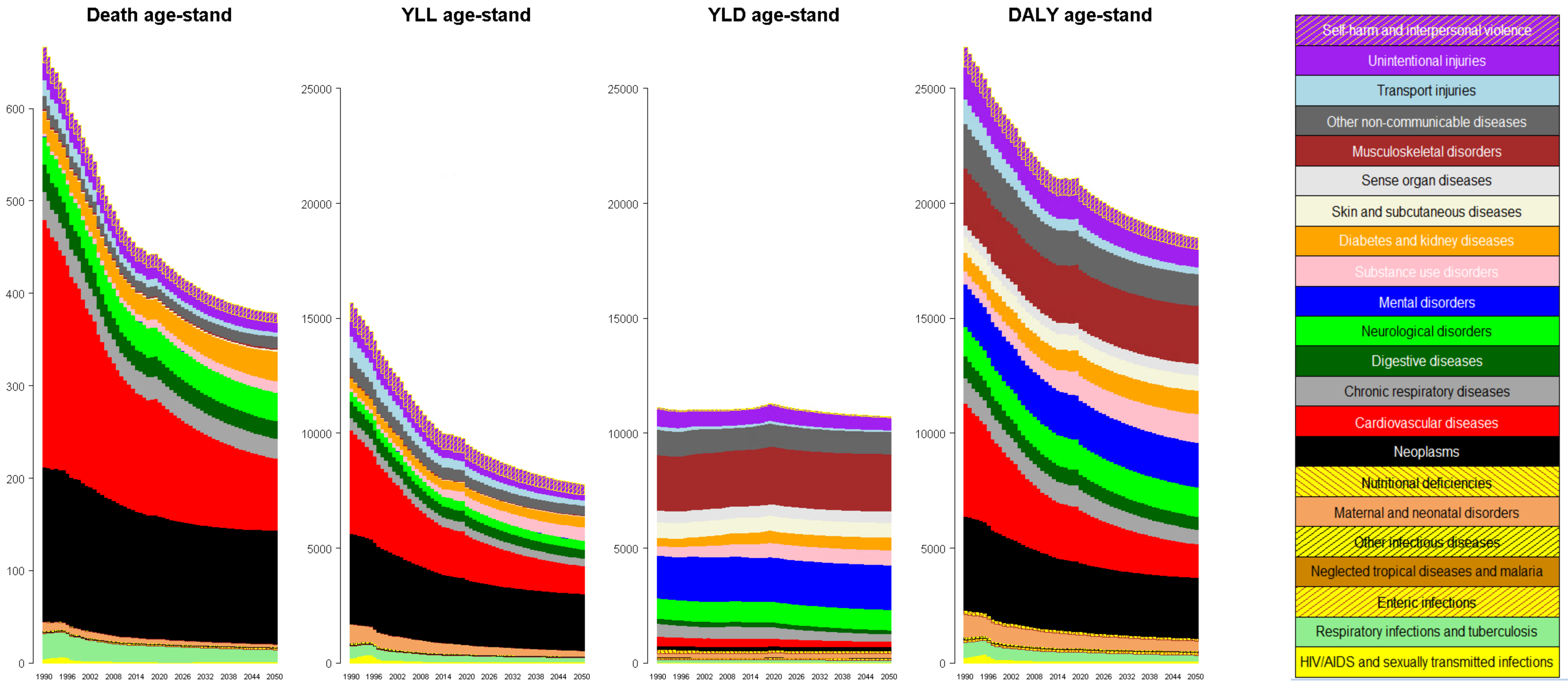
Global age-stand rates: death, YLL, YLD, DALY 1990 - 2050 – GBD 2019



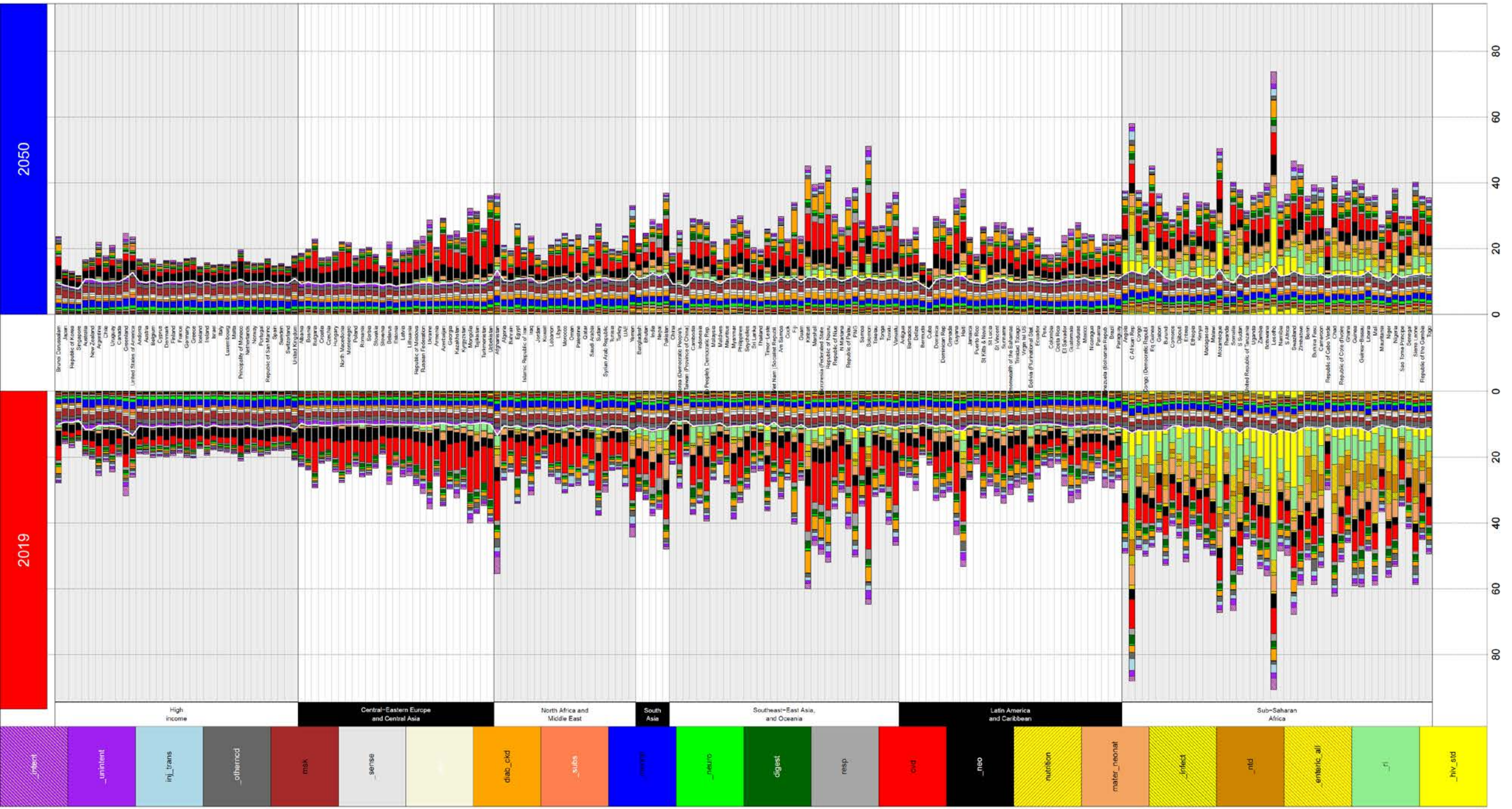
Sub-Saharan Africa ASR 1990 - 2050 : death, YLL, YLD, DALY – GBD 2019



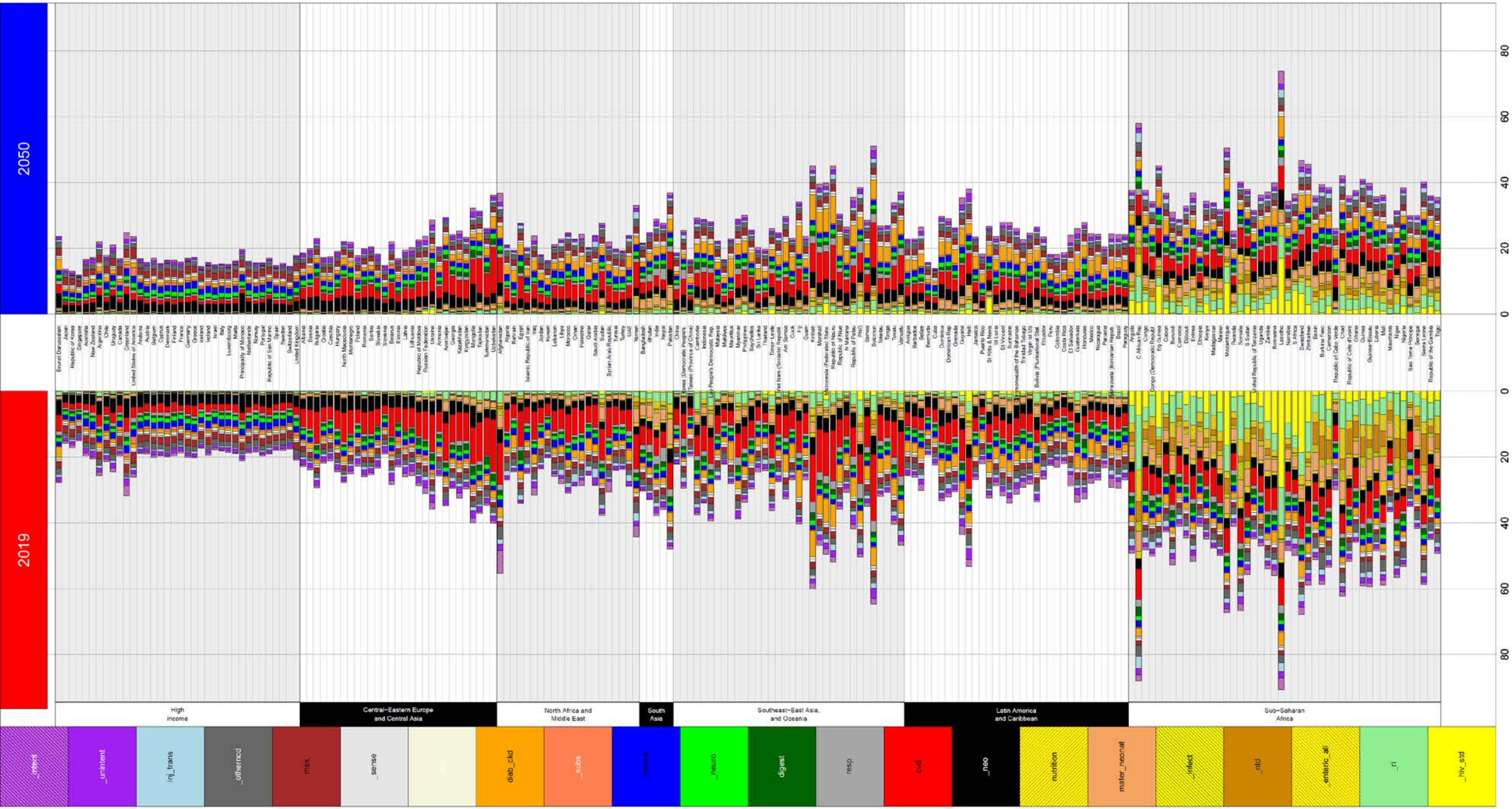
High-income age-stand rates: death, YLL, YLD, DALY 1990 - 2050 – GBD 2019



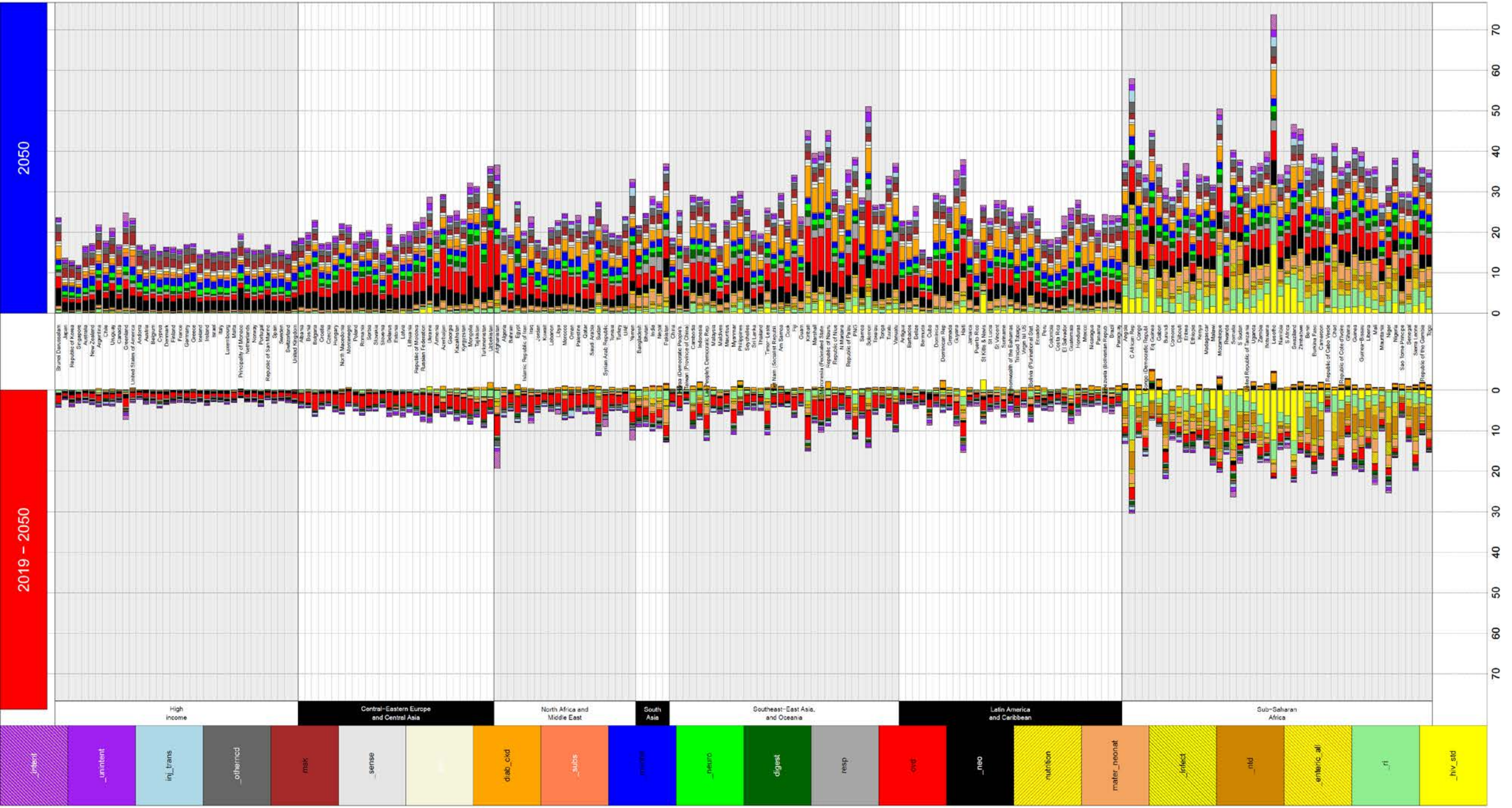
GBD2019 v1 − All−in−one−DALY plot − YEAR=2019 vs YEAR=2050 − (YLD + YLL)/100 − 25FEB2021



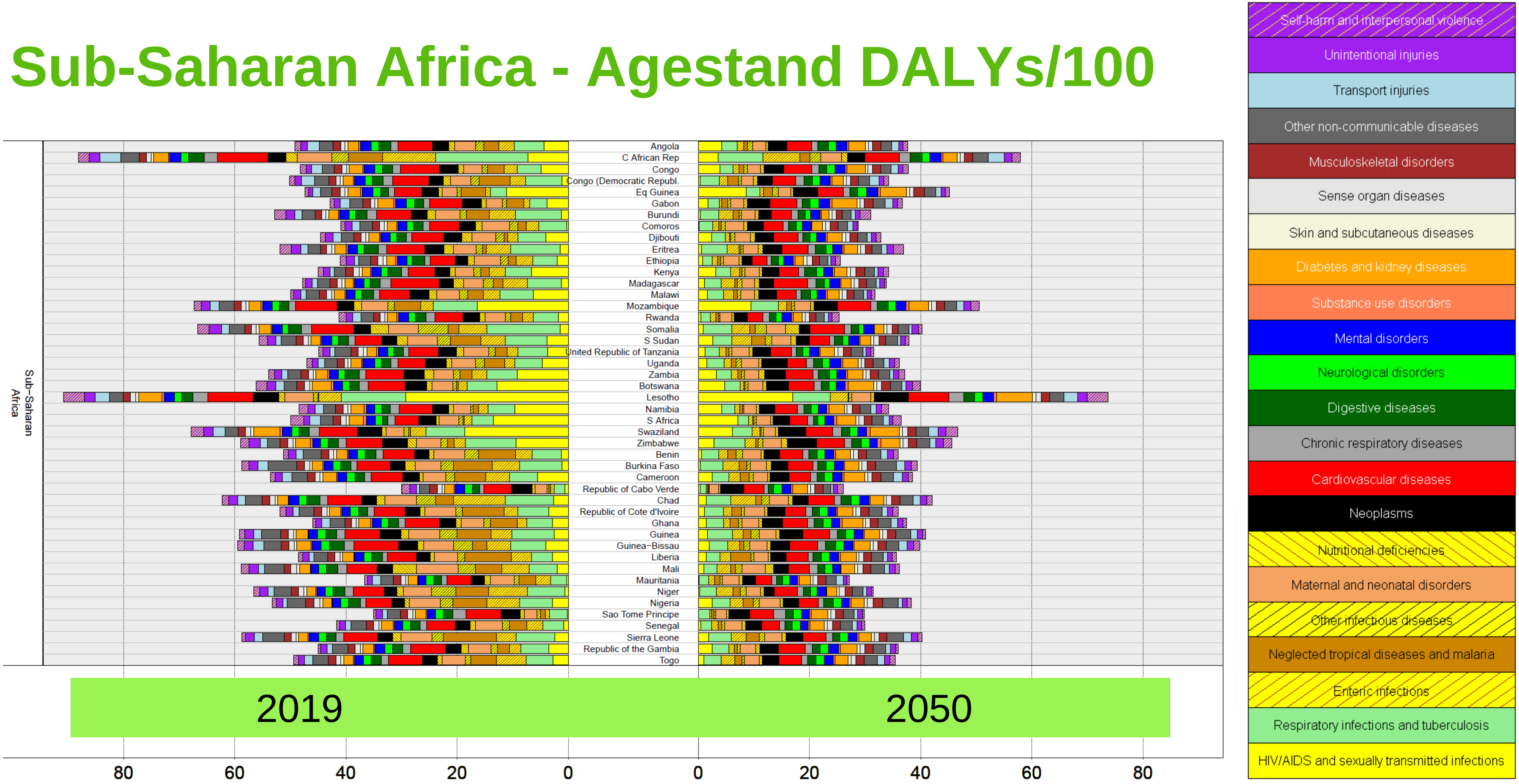
GBD2019_v1 DALYs plot YEAR=2019 vs YEAR=2050 − DALY/100 − 25FEB2021



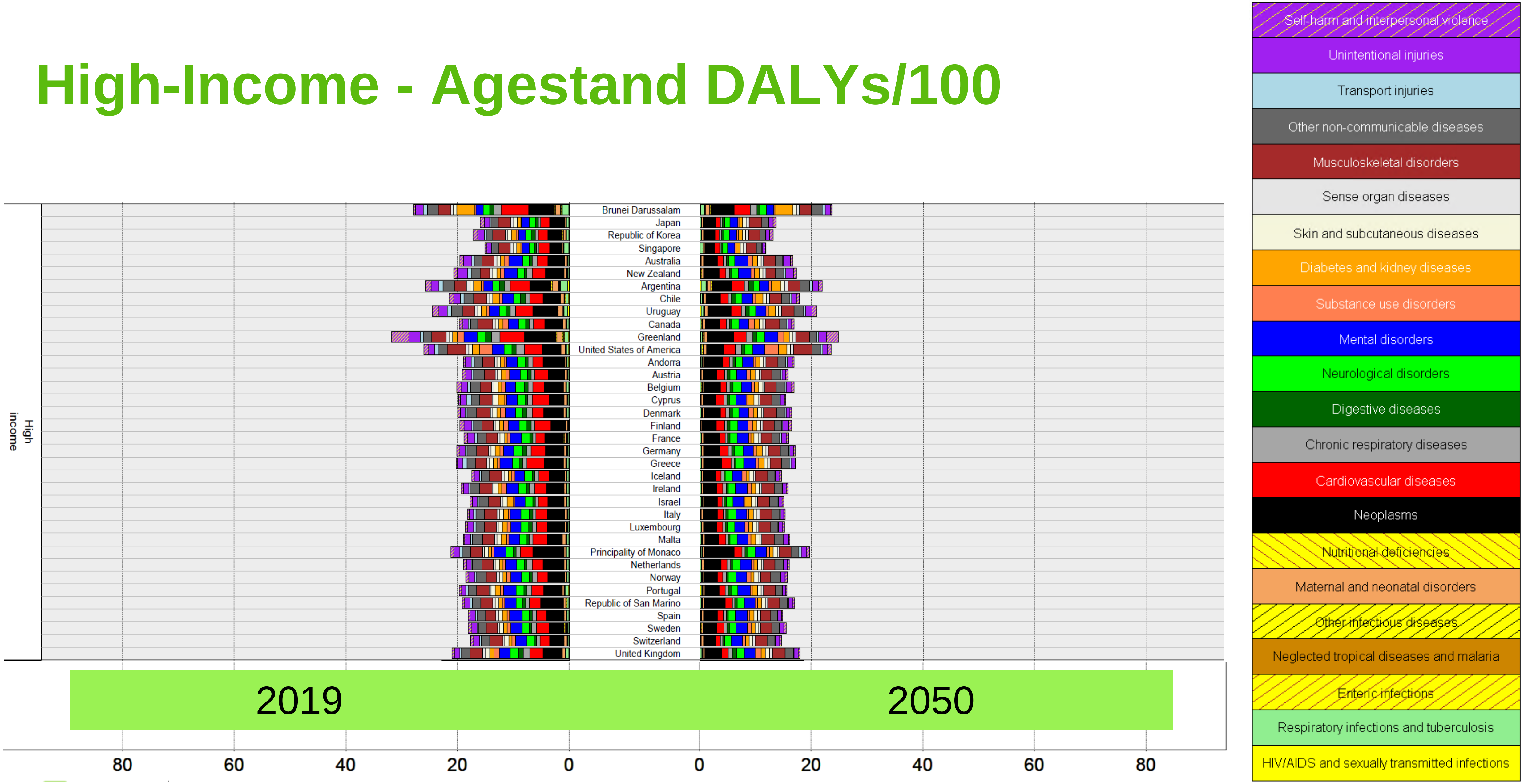
GBD2019 version_1 DIFFERENCE YEARS=2019 AND YEAR=2050 VS YEAR=2050 − DALY/100 − 25FEB2021



Sub-Saharan Africa - Agestand DALYs/100



High-Income - Agestand DALYs/100



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, life expectancy, HALE, 360 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 the GBD comparative risk assessment and Sociodemographic index
- A unique feature of our framework is the potential to produce tailored scenarios of risk factors and interventions (eg, policy scenarios: 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)