

# UPDATED WHO PROJECTIONS OF MORTALITY AND CAUSES OF DEATH 2016-2060

Colin Mathers

Global Health Consultant

## 1. Overview

Following the release of the WHO Global Health Estimates of deaths by cause, age, sex and country for years 2000-2016 (1), WHO projections of mortality and causes of death have been updated and extended for years 2017-2060 (2). These projections are an update of previous projections released in 2006 (3), 2008 (4) and 2013 (5), and use methods similar to those applied in the original WHO-World Bank Global Burden of Disease study (6). A set of relatively simple models were used to project future trends in age-sex specific mortality rates for a “business-as-usual” scenario, based largely on projections of economic and social development, and using the historically observed relationships of these with cause-specific mortality rates. Projected death rates were converted to numbers of deaths using the median population projections of the World Population Prospects 2017 (7). The following Section 2 briefly summarizes these projection models and some revisions made for this update.

Additionally, all the projection covariates have been revised and updated as described in Section 3 below. In the original projections, separate projection models were developed for HIV/AIDS, tuberculosis, lung cancer, diabetes mellitus and chronic respiratory diseases (3). These models have been revised and updated for this update as described in Section 4. Additional special projection models have also been developed for malaria, maternal deaths, road injury, homicide, natural disasters and war and conflict. Section 5 provides an overview of the global and regional results for cause of death projections from years 2017-2060, with some comparisons to the most recent all-cause mortality and life expectancy projections by the UN Population Division.

## 2. Revisions to the major cause projection models

Projections models for males and females and for seven age groups -- 0-4, 5-14, 15-29, 30-44, 45-59, 60-69, and 70 years and older -- were developed for 10 cause-of-death clusters with regression equations (3) of the form:

$$\ln M_{a,k,i} = C_{a,k,i} + \beta_1 \ln Y + \beta_2 \ln HC + \beta_3 (\ln Y)^2 + \beta_4 T + \beta_5 \ln SI \quad (1)$$

where  $C_{a,k,i}$  is a constant term,  $M_{a,k,i}$  is the mortality level for age group  $a$ , sex  $k$ , and cause  $i$ , and  $Y$ ,  $HC$  and  $T$  denote GDP per capita, human capital and time, respectively. “Human capital” refers to the average years of schooling for adults aged 25 years and over. Time (measured in years) is a proxy measure for the impact of technological change on health status. This variable captures the effects of accumulating knowledge and technological development, allowing the implementation of more cost-effective health interventions, both preventive and curative, at constant levels of income and human

capital. The “smoking impact” variable *SI* is the component of observed lung cancer mortality that is attributable to tobacco smoking (8). The log of the smoking impact *SI* is included in the equation only for malignant neoplasms, cardiovascular diseases, and respiratory diseases. This basic, relationship makes no specific assumptions about causality, or the relationships between these more distal socio-economic factors and more proximate determinants of mortality rates such as environmental, life style and physiological risk factors. Separate regression equations are used to relate age- and sex-specific mortality rates for 132 detailed causes to the age- and sex-specific mortality rates from corresponding cause-clusters.

For earlier versions of these projections, the projection regression equations for child deaths were recalibrated so that back projections of child mortality rates from the early 2000s to 1990 matched observed trends, by setting the regression coefficient for time to zero for Sub-Saharan Africa, and low values for other low-income regions. These adjustments were removed for this update, as child mortality declines accelerated in low income region during the MDG period from the early 2000s to 2015.

Earlier versions of these projections also took into account recent trends in death registration data for high income countries for ischaemic heart disease, cerebrovascular disease, tuberculosis, suicide and homicide using a loglinear Poisson regression model for country-years of data from 1985 onwards. In the original projections, country-specific trends were given 100% weight for the first projection year, then a weight decreasing by a factor of 0.85 for each subsequent year, until after around 12 years, the trend was fully determined by the regression models’ trends. For this update, recent trends were estimated for all regions and for all causes based on the GHE2016 estimates of causes of death for years 2000-2016 (1). Average annual rates of change (ARR) were truncated to the range -50% to +25% and ARR greater than zero were assumed to decline by 10% per year from 2017 to 2026. Final projection ARR gave country-specific trends 100% weight for 2017, decreasing smoothly to zero weight in 2027, after which trends were fully determined by the regression models.

### **3. Major cause group covariates**

#### **3.1 Gross domestic product (GDP)**

Latest World Bank estimates of GDP per capita for years 2016 and 2017 (9) were used as the starting point for projections of GDP per capita in constant 2011 PPP international dollars (purchasing power parity adjusted). Projections were updated using recent projections of real growth per annum in income per capita from OECD (10), and International Futures (IFs) (11). Table 1 compares the updated projections used here with those of IFs (11), the OECD (10), Price Waterhouse Coopers (12) and the World Bank (13).

For a number of oil-exporting countries, the above projections result in very high incomes per capita by the end of the century (for example, Qatar would have the highest GDP per capita in the world). This is almost certainly unrealistic for most such countries, given the likelihood of depletion of oil reserves

during the next 30-60 years for most. Based on World Bank estimates of oil rents for the year 2016 (14), the following countries were identified as having 12.5% or more of GDP per capita attributable to oil export: Kuwait (44%), Iraq (42.4%), Saudi Arabia (26.4%), Oman (24.7%), Congo, Rep. (19.4%), Azerbaijan (17.5%), Qatar (16.3%), United Arab Emirates (14.5%), Iran, Islamic Rep. (13.6). Timor-Leste (20%) and Equatorial Guinea (15%) were excluded from this list.

*Table 1. Average annual growth rate (%) in GDP per capita (2011 PPP\$), 2016-2060*

	Projections BAU Scenario	IFs (2017)	OECD(2014)	PWC (2017)	WB (2006)
World	1.55	1.61	1.82	1.65	1.81
OECD (a)	1.41	1.26	1.69	1.50	
BRICS (b)	2.57	2.61	2.95	2.89	

(a) 34 OECD Members as of 2014

(b) Brazil, Russia, India, China, South Africa

For these countries, the non-oil GDP per capita in 2016 was assumed to follow the growth rates projected as described above. The oil proportion of GDP per capita was projected to grow at half the growth rate of the non-oil GDP from 2016 to 2030. From 2030 onwards, it was projected to decline at 1.5% per annum. Total GDP per capita for these oil countries was then calculated as non-oil GDP per capita plus half the projected oil GDP per capita (to account for the likelihood that a significant portion of oil rent in these countries does not flow through to general economic and social welfare).

Table 2 summarizes annual average growth rates for the GDP per capita projections.

*Table 2. Average annual growth rates in projected GDP per capita (PPP \$ 2011 base)*

Region	1960-1980	1980-2000	2000-2015	2015-2030	2030-2060
High income OECD <sup>a</sup>	3.22	2.26	1.06	1.36	1.50
Afr	0.92	-1.06	2.64	0.86	1.94
Amr	2.83	0.37	1.85	1.21	1.14
Emr	2.03	0.94	2.38	1.12	0.71
Eur	3.01	-0.74	3.83	1.60	1.39
Sear	1.97	3.34	4.58	3.48	2.68
Wpr	2.59	6.76	8.12	3.56	2.26
World	2.35	1.42	2.43	1.74	1.45

(a) High income OECD countries are excluded from the WHO Regions rows shown above

### 3.2 Human capital (HC)

The education covariate (referred to as human capital or HC) is the average number of years of education received by people ages 25 and older, with separate estimates and projections for men and women. Historical data were derived from the Barro-Lee dataset for years 1950-2010 (15, 16).

*Table 3. Projected average years of schooling, ages 25 and over, by region, 2016, 2030 and 2060.*

Region	Men			Women		
	2016	2030	2060	2016	2030	2060
High income OECD	11.9	12.8	14.5	11.8	12.9	14.8
Afr	6.0	6.7	8.2	5.3	6.1	8.2
Amr	8.4	9.4	11.1	8.7	9.9	12.1
Emr	7.4	8.3	9.9	6.3	7.5	9.8
Eur	10.3	11.0	12.5	10.0	10.8	12.7
Sear	6.2	7.8	10.8	5.5	7.3	10.9
Wpr	8.6	9.5	11.5	8.2	9.3	11.9

Business-as-usual projections of the historic Barro-Lee dataset were based on the base scenario projections from Version 7.31 of International Futures (11). The following table summarizes average HC for high income OECD countries and other countries by WHO Region for years 2016, 2030, and 2060.

### 3.3 Smoking impact (SI)

Smoking impact (SI) is defined as the lung cancer death rate attributable to smoking and is calculated for historical data as the total lung cancer death rate minus the nonsmoker lung cancer rates (3). Non-smoker lung cancer rates used previously were updated using more recent data from the American Cancer Society Cancer Prevention Study II (ACS-CPS II) (17) and two large Chinese prospective studies (18).

Since smoking-caused lung cancer trends follow smoking prevalence trends with a lag of around 25 years, smoking impact (SI) projections were revised using historic and projected trends in smoking prevalence and average cigarette consumption per capita.

WHO has recently published updated estimates and trends for current tobacco smoking prevalence trends among males and females aged 15 years and over, for the period 2000 to 2025 (19). The Global Burden of Disease Study 2016 estimated adult smoking prevalence for ages 15 for years 1980-2016 (20). International Futures (IFs) estimated tobacco smoking prevalence in adults aged 30 years and over from

1960 onwards and projected it forward to 2100 (11). The three inputs were used to prepare a consistent of estimates and projections of current smoking prevalence for the period 1960-2025.

Country-sex specific average annual rates of change (ARC) in current smoking prevalence for the period 2005-2025 were calculated using regression analysis. For countries where smoking prevalence was declining, the estimated ARC was used to project smoking prevalence forward from 2025 to 2060. For years beyond 2030, the ARC was set to zero if the smoking prevalence dropped to 1% or below. For high income countries, and countries in the WHO European Region, ARC was set to zero if the smoking prevalence dropped to 4% or below.

For countries where the sex-specific ARC was positive (rising trend), the trend was assumed to peak and then start to decline after a certain number of years. This was done using global average “epidemic curves” constructed from the ARR time series for countries with rising and then falling smoking prevalence during the period 1990-2010, time-shifted to all peak at the same time. Separate epidemic curves were constructed for countries with positive ARR in the following bands: 1.0 -1.005, 1.005 -1.01, 1.01 – 1.02, 1.02 – 1.05, and >1.05. Estimated and projected smoking prevalences for the period 2000-2060 are summarized below in Table 4.

*Table 4. Smoking prevalences (%) for males and females aged 15 years and over, by region, 2000-2060*

Region	Males				Females			
	2000	2015	2030	2060	2000	2015	2030	2060
High income countries	39.8	28.5	21.3	13.0	23.3	18.2	14.3	9.0
Afr	21.4	18.4	16.4	12.0	3.7	2.8	2.2	1.8
Amr	30.9	21.9	16.6	11.2	15.3	9.6	6.3	3.3
Sear	39.3	29.4	23.5	15.1	4.3	3.2	2.8	2.0
Eur	59.2	47.5	38.3	25.6	16.7	16.0	15.6	12.3
Emr	32.1	31.4	30.9	24.7	4.9	4.6	4.0	3.2
Wpr	56.0	49.5	44.1	33.1	3.4	2.7	2.2	1.5
World	41.6	32.9	27.1	18.2	9.2	6.8	5.3	3.4

	Persons			
	2000	2015	2030	2060
World	25.5	20.0	16.3	10.8

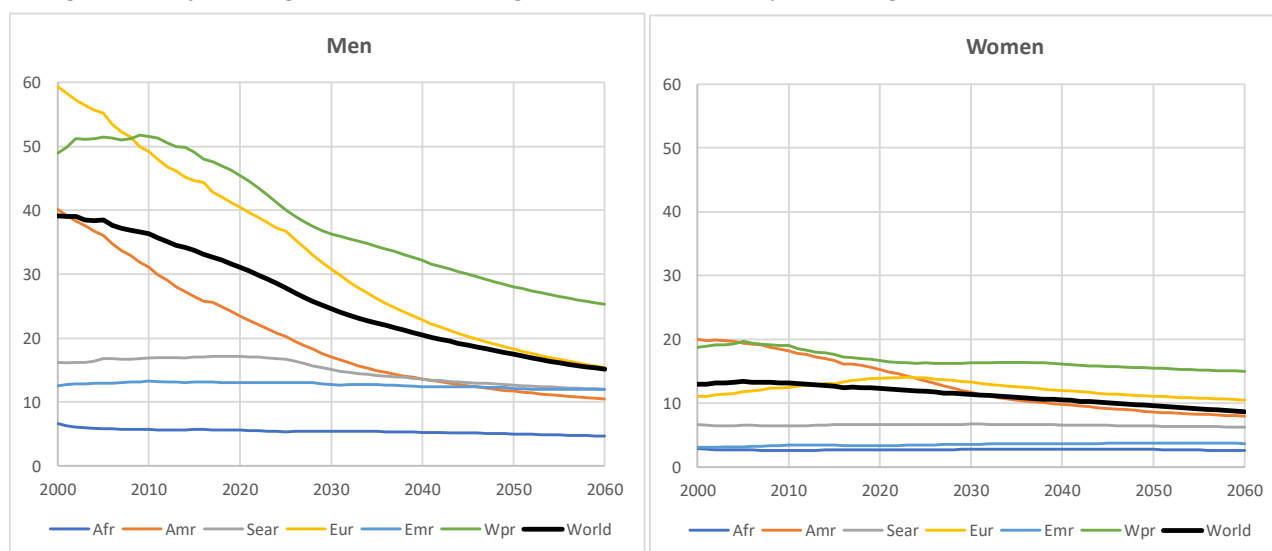
WHO has previously estimated the apparent annual consumption of cigarettes per capita for years 1940-2008 from production and trade data (21). This was updated to the period 1940-2016 using more recently compiled IHME datasets for cigarette consumption for periods 1970 to 2005 (22) and 1980-2016 (20). These estimates were combined with the smoking prevalence estimates to prepare estimates of cps, the average cigarettes per smoker per day for the period 1950 to 2016. The average annual change in cps for the most recent five year period 2011-2016 was calculated for each country and

truncated to the range -0.5 to +1 and used to project cps for 2017. Then cps was projected forwards to 2030 assuming that the annual change for each year was 85% of the change for the previous year. From 2030 onwards, cps was assumed to remain constant.

Age-standardized smoking impact (SI) was calculated from lung cancer death rates derived from death registration data from 1950 to 2016 in the WHO Mortality Database (23) plus lung cancer mortality estimates for 183 countries for years 2000-2016 in the WHO GHE2016 (24). In all, there were 2968 data points for 97 countries before year 2000, and 5918 data points for 183 countries from 2000-2016. The log of the age-standardized SI was then regressed against smoking prevalence and average cigarettes per smoker per day for 25 years earlier for males and females separately. Interaction terms for both independent variables with region were included for the African region, Asian region (Western Pacific plus South East Asian) and Eastern Mediterranean region. This allowed the relationships between smoking prevalence and cigarettes per day with smoking impact to vary by region. Data were weighted for quality as follows: high quality death registration data were given a weight of 3, low quality death registration data a weight of 2, and GHE2016 data for countries without death registration data were given a weight of 1.

The regression for men had an overall  $r^2$  of 0.94 and that for women an  $r^2$  of 0.82. Varying the lag between smoking prevalence and cigarettes per day from 25 years to 30 years made minimal difference to the  $r^2$  values or the regression coefficients. These regressions were then used to project age-standardized SI rates for men and women from 2017 to 2060 for all countries. The annual projected rates of change in the age-standardized SI rates was then applied to the age-specific SI rates in the base year 2016 in order to project SI by country, age and sex to 2060. The resulting regional age-standardized total lung cancer death rates for years 2000 to 2060 are shown below for WHO Regions and the world.

*Figure 1. Projected age-standardized lung cancer death rates by WHO Region and sex, 2000-2060*



## 4. Specific cause models

### 4.1 Tuberculosis

Business-as-usual projections of tuberculosis (TB) mortality rates were updated based on the most recent time series for TB deaths as published in the WHO Global Tuberculosis Report 2017 (25). Average annual rates of change (ARC) in country-sex-age specific TB death rates (for age group 0-4, 5-14, 15-29, 30-44, 45-59, 60-69, 70-79. And 80+) were estimated using a Poisson regression on TB deaths for the period 2000-2016 and weights giving more importance to recent years (weight =  $0.85^{(2017-\text{year})}$ ). For regressions where there were less than 15 total TB deaths for 2005-2016, regional ARC were used. The regions used were: high-income countries, WHO African Region, WHO American Region, WHO European Region, Other regions. Russia, China and India were kept separate, as these three countries have the largest numbers of drug-resistant TB cases (47% of the global total) (25).

ARR percentiles were then estimated by region and age, excluding countries with populations below 500,000. Outlier ARR beyond the 10<sup>th</sup> and 90<sup>th</sup> percentiles by region and age were replaced by the 10<sup>th</sup> and 90<sup>th</sup> percentiles. ARR were projected forward for years 2017-2030 assuming that ARRs below the 25<sup>th</sup> percentile converged on the 25<sup>th</sup> percentile in 2030. Similarly, ARRs above the 75<sup>th</sup> percentile converged on the 75<sup>th</sup> percentile in 2030.

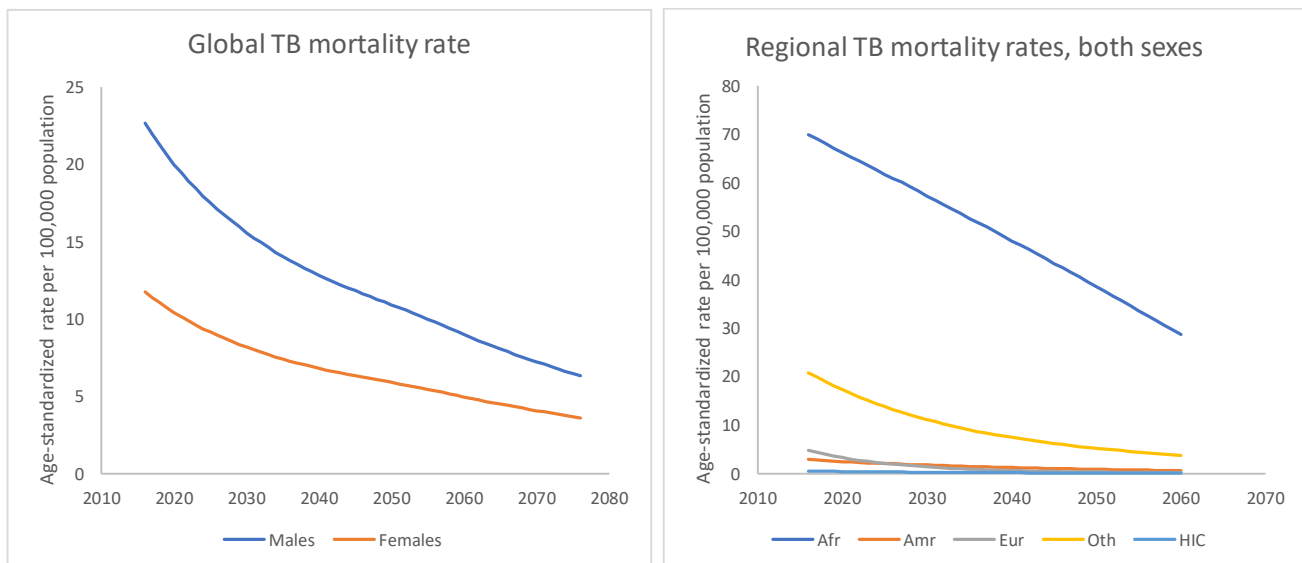
For projecting beyond 2030, ARR were calculated for regional age-standardized death rates by sex. Outlier rates of -7 to -10% for Russia and European Region (excluding high income countries) were then projected to trend to the 75<sup>th</sup> percentile regional ARR rate of -6.7% over the period 2031 to 2045. Similarly, ARR greater than the regional 25<sup>th</sup> percentile of -1.9% were assumed to trend to -1.9% by 2045. For the period 2046-2060, ARR below the regional median age-standardized ARR of -5.2% were assumed to trend to that value in 2060. ARR higher than -3.4% (the 2007-2016 global average age-standardized ARR) were assumed to trend to that value in 2060.

The following graphs summarize the global and regional TB mortality projections. These are business-as-usual projections of current trends in TB mortality rates and do not include the scale-up in annual rates of change that would be required to reach TB targets set in the WHO End TB Strategy (26), or for the Sustainable Development Goals (25). To reach the targets set out in the End TB Strategy, the annual decline in global TB incidence rates must first accelerate from 2% per year in 2015 to 10% per year by 2025. Secondly, the proportion of people with TB who die from the disease (the case-fatality ratio) needs to decline from a projected 15% in 2015 to 6.5% by 2025 (27). According to the 2017 Global Tuberculosis Report (25), “an unprecedented acceleration in the rate at which TB incidence falls globally is required if the 2030 and 2035 targets are to be reached. Such an acceleration will depend on a technological breakthrough that can substantially reduce the risk of developing TB disease among the approximately 1.7 billion people who are already infected with *Mycobacterium tuberculosis*. Examples include an effective post-exposure vaccine or a short, efficacious and safe treatment for latent TB infection.”

However, these business-as-usual projections are somewhat more optimistic than a recent more sophisticated projection model which attempted to take account of the impact of population ageing and

demographic change on TB transmission dynamics, by explicitly taking account of transmission contact patterns across ages (28). That model was applied to four countries Ethiopia, Indonesia, India and Nigeria. These four countries accounted for 52% of global TB deaths in 2016. The transmission model projected a 30% decline from 2015 to 2050 in the overall TB death rate for these four countries combined, compared to 50% from the business-as-usual projections described here.

*Figure 2. Global and regional projected trends in age-standardized TB mortality rates, 2016-2060.*



Because of population growth and ageing, the projected global decline in age-standardized TB death rate of 59% from 2016 to 2060 translates to a projected 23% decrease in the absolute number of TB deaths from 1.29 million in 2016 to 997 thousand in 2060. This is a long way from the End TB target of a 95% decline in global TB deaths by 2035, highlighting the need for dramatic increases in rates of decline to achieve these targets.

## 4.2 HIV/AIDS

UNAIDS has released updated 2018 estimates of HIV death rates, which take into account the continued scale up of antiretroviral therapy coverage (29). A dataset of age-sex specific death rates by country provided by UNAIDS for years 1985-2017 was used to prepare business-as-usual projections of HIV .

Average annual rates of change (ARC) in country-sex-age specific HIV death rates (for age group 0-4, 5-14, 15-29, 30-44, 45-59, 60-69, 70-79. And 80+) were estimated using a Poisson regression on HIV deaths for the period 2008-2017 with weights giving more importance to recent years (weight =  $0.85^{(2017-\text{year})}$ ). For regressions where there were less than 15 total HIV deaths for 2008-2017, regional ARC were used. The regions used were: high-income countries, WHO African Region, WHO American Region, WHO European Region, Other regions.

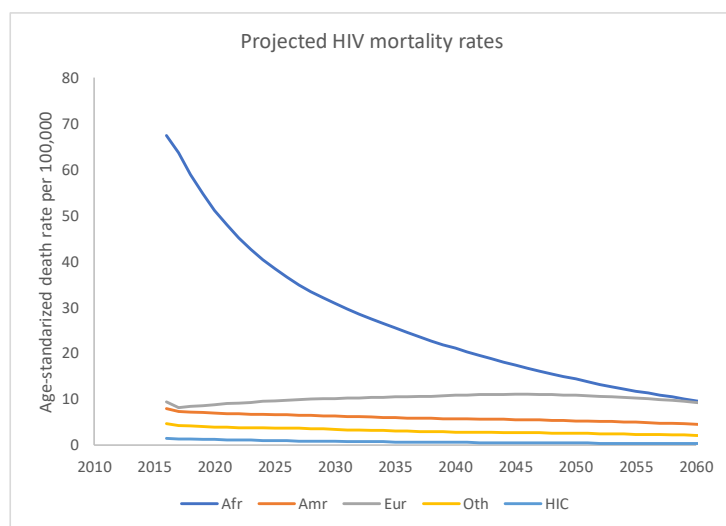


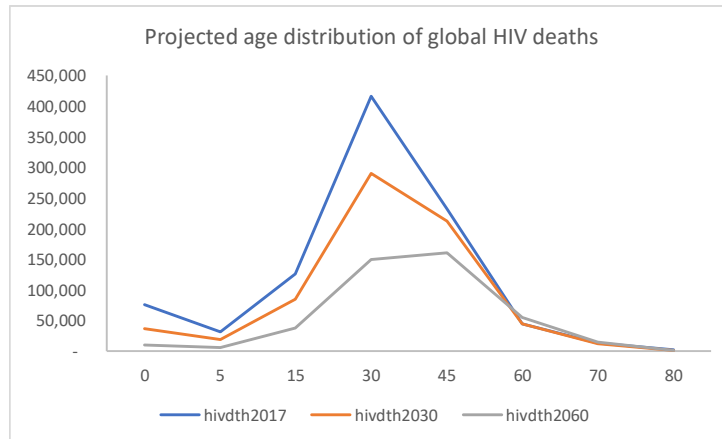
ARR percentiles were then estimated by region, sex and age, excluding countries with populations below 500,000. Outlier ARR beyond the 10<sup>th</sup> and 90<sup>th</sup> percentiles by region and age were replaced by the 10<sup>th</sup> and 90<sup>th</sup> percentiles. ARR were projected forward for years 2017-2030 assuming that ARRs below the 25<sup>th</sup> percentiles converged on the 25<sup>th</sup> percentiles in 2050. ARRs above the 50<sup>th</sup> percentiles also converged on the 50<sup>th</sup> percentiles in 2050 for all regions.

For projecting beyond 2030, the age-sex-region specific 50<sup>th</sup> percentiles of ARR were replaced by -0.5% if they were greater than -0.5% and by -4% if they were less than -5%. The 25<sup>th</sup> percentile was replaced by -2.5% if it was greater than -2.5%. were then projected to trend to the 75<sup>th</sup> percentile regional ARR rate of -6.7% over the period 2031 to 2045. Similarly, ARR greater than the regional 25<sup>th</sup> percentile of -1.9% were assumed to trend to -1.9% by 2045. For the period 2046-2060, ARR below the regional median age-standardized ARR of -5.2% were assumed to trend to that value in 2060. ARR higher than -3.4% (the 2007-2016 global average age-standardized ARR) were assumed to trend to that value in 2060. Beyond 2050, age-specific ARRs were assumed to converge on -7.5% for under 5s, -5% for ages 5-44, -4.5% for ages 45-59, -2.5% for ages 60-79 and -7.5% for ages 80+.

The following Figure shows the projected age-standardized mortality rates by region for years 2018-2060 and the evolution of the age pattern of HIV deaths towards older ages over that period. Total HIV deaths are projected to decline from 987,247 in 2016 to 702,700 in 2030 and 435,800 in 2060.

*Figure 3. Regional projected trends in age-standardized HIV mortality rates and age pattern, 2016-2060.*





### 4.3 Malaria

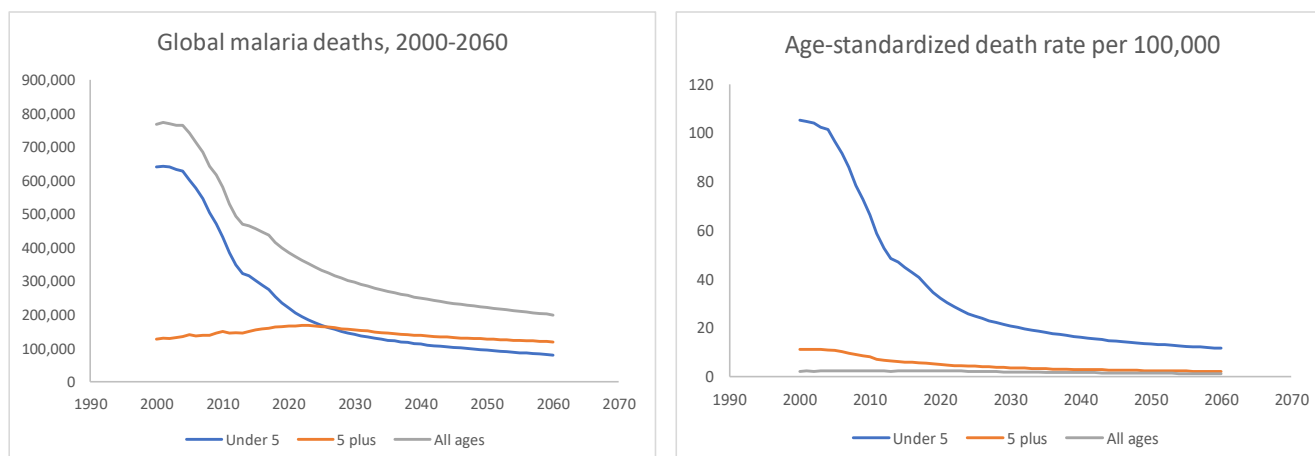
For 31 countries in the African Region where malaria comprises 5% or more of all deaths in children under 5, child malaria deaths under age 5 were projected based on projections of malaria parasite prevalence (PfPR). PfPR is the proportion of the population carrying asexual blood-stage parasites and is considered as an indicator of malaria transmission intensity (30). Updated national time series for years 2000-2017 were produced by the Malaria Atlas Project at Oxford University in close collaboration with WHO (31).

Average annual rates of change (AAR) in PfPR for the period 2008-2017 were projected to 2030 assuming that ARR below the median ARR converged to the median (-6.3% per annum), ARR between the median and 60<sup>th</sup> percentile converged to the 60<sup>th</sup> percentile (-3.5%), and ARR above the 60<sup>th</sup> percentile converged to the 75<sup>th</sup> percentile (-1.6%). From 2031-2050, ARR below the median were assumed to converge to the 60<sup>th</sup> percentile, and ARR above the 60<sup>th</sup> percentile were assumed to converge to the 75<sup>th</sup> percentile. From 2050 to 2100, all ARR were assumed to converge to the 75<sup>th</sup> percentile.

The under 5 malaria mortality rate (U5MMR) was predicted from the projected PfPR based on a regression of U5MMR against PfPR for years 2000-2017 ( $r^2 = 0.89$ ). The over 5 malaria mortality rate was predicted from U5MMR using the methods documented in the 2017 World Malaria Report (32). These projected rates were then used to project 2016 age-sex-specific malaria mortality rates forward to 2100 for the 31 high malaria countries in Africa. Malaria death rates for other countries were projected using the major-cause projection model results for Group 1 causes.

The following two graphs show projected total malaria deaths by year, and projected trends in global U5MMR and age-standardized death rate for ages 5 years and over.

*Figure 4. Projected trends in malaria mortality, by age and all ages, 2016-2060.*



#### 4.4 Maternal deaths

For estimation of trends in maternal mortality ratios, WHO has used a covariate-based regression model within a Bayesian framework in recent years, where the proportion of all deaths of women of reproductive age due to maternal causes (PMDF) is modelled as

$$PMDF = \exp(-0.30662 * \ln(GDP/1.13348) + 0.96681 * \ln(GFR) - 0.84051 * SAB)$$

where the three covariates are defined as

<i>GDP</i>	GDP per capita in 2005 PPP\$
<i>GFR</i>	General fertility rate (live births per woman aged 15-49 years)
<i>SAB</i>	Skilled attendant at birth (as a proportion of live births)

and the numeric coefficients are those obtained from fitting the above equation to the maternal mortality data for the 2014 UN Interagency Report on Trends in Maternal Mortality (33, 34). The numeric coefficient 1.13348 converts the projected GDP time series in 2011 PPP\$ to 2005 PPP\$.

The above equation was used with projected covariates to project rates of change of PMDF, and these were used to project baseline 2016 PMDF from 2016 to 2060. GFR projections for years 2016 to 2060 were based on the median projections of fertility in the World Population Prospects 2017 (7). Historical time series of SAB by country for years 1985-2015 (35) were projected forward to 2060 using a regression of  $\logit(SAB)$  against  $\ln(GDP)$  together with the business-as-usual GDP projections.

#### 4.5 Diabetes mellitus

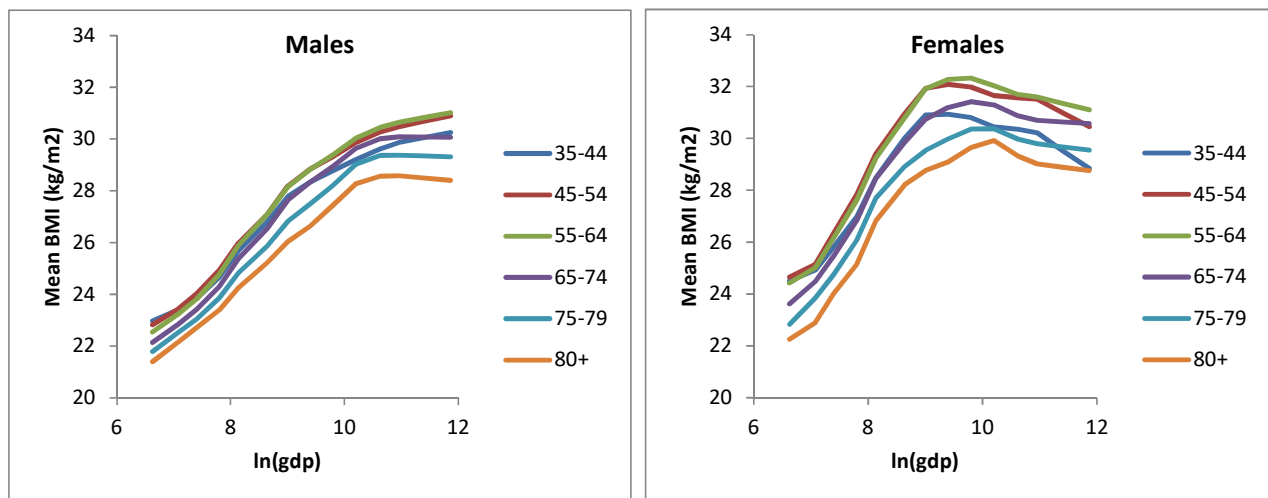
Previous projections of diabetes mortality were based on projections of the prevalence of overweight and obesity, together with the increased risk of diabetes associated with overweight and obesity (3). Relative risks for diabetes mellitus mortality associated with increasing levels of body mass index ( $kg/m^2$ ) were revised downwards based on latest information from the Asia Pacific Cohorts study (36). For the business-as-usual projections, the diabetes mortality rate associated with the counterfactual BMI

distribution (mean 21 and standard deviation 1 kg/m<sup>2</sup>) was assumed to be declining at the same rate as 'Other Group II' causes.

BMI distributions by age, sex and country for years 1980-2008 were estimated by Finucaine et al (37). The distributions were assumed normal and characterized in terms of mean and standard deviations. Updated time series and projections of means and standard deviations for years 2010-2025 were prepared by Kontis et al (38). These projections simply extended the trends for the most recent period 2006-2010. We used these projections for WHO Member States for age groups 30-34, 35-44, 45-54, 55-64, 65-74, 75-79, 80+.

In order to extend these projections beyond 2025, we assumed that the recent age-sex-specific trends would continue but that mean BMI increase would be limited and in the long run would not exceed separately estimated mean BMI "ceilings" as functions of GDP per capita. Estimates of mean BMI for years 2000-2010 for countries excluding Pacific Islands and low- and middle-income countries of the Eastern Mediterranean Region were used to estimate the 90<sup>th</sup> percentile mean BMI for each age-sex group for grouped categories of GDP per capita. The ceiling mean BMIs were then estimated as a function of GDP per capita by linear interpolation (see Figure B.1)

Figure 5. BMI "ceilings" as a function of  $\ln(gdp)$ . where  $gdp$  is GDP per capita in 2011 constant PPP\$



#### 4.6 COPD and asthma

Projections for chronic respiratory disease mortality were adjusted for the updated projected changes in smoking impact SI, using methods described previously (3). The non-smoker rates for all these chronic respiratory diseases were assumed to be declining with socioeconomic growth at the same rate as 'Other Group II' causes.

#### 4.7 Road injury

The relationships between injury mortality rates and the main projections covariates of income per capita and human capital are not straightforward and the major cause regression models did not perform well for road injury or other injury causes (3). For low income countries, road injury death rates tend to rise with economic growth and higher levels of motor vehicle ownership, whereas for higher income countries, they tend to fall with increased economic growth (39). We make use of Smeed's Law (40) to project road injury mortality rates as a function of average vehicles per capita (VPC), at first rising with increasing VPC and then falling:

$$M_{a,k,t} = M_{a,k,0} \times Smeed_a \times \frac{vpc}{1000} \times \exp\left(-Smeed_b \times \frac{vpc}{1000}\right)$$

where  $vpc$  is vehicles per 1000 population, and  $Smeed_a$  and  $Smeed_b$  are two numerical coefficients.

Vehicles per capita time series for all countries were prepared for the years 1950-2014 drawing on data from the International Road Federation (41), IFs (11), and the WHO Global Surveillance of Road Safety Reports of 2013 and 2015 (42, 43). The resulting dataset is reasonably complete for most recent years, but much fewer data are available for earlier years. Overall, the dataset contains 3,729 observations for 197 countries.

VPC has been projected from income per capita (GDP) using the following functional form (40):

$$vpc = vpc_{max} \times \exp(\alpha \times \exp(\beta * GDP/1000))$$

where  $vpc_{max}$  is a country-specific maximum vehicles per capita ranging from 852 per 1000 downwards depending on population density and per cent urban. Country-level values calculated by Dargay, Gately and Sommer (44) are used.

The parameters  $\alpha$  and  $\beta$  were re-estimated using the updated VPD and GDP datasets by regressing

$$y = \ln(-\ln(vpc/1000))$$

against GDP using a linear regression model with random country effects. The estimated equation was then used to project VPC from the projected GDP time series. For five mainly very small countries where  $vpc$  exceeded  $vpc_{max}$  in 2014,  $vpc$  was projected to decline to  $vpc_{max}$  over the long-term.

Koren and Borsos (45) re-estimated the parameters for Smeed's Law by region, using data for 137 countries in 2007. They found that fatality rates peaked at a vehicle ownership level of around 200 to 250 per 1000 population, with some variations in levels and trends across regions. They also found that for countries well above the fatality turning point, Smeed's law is too pessimistic and rates of decline are higher than projected (for example in many high income countries).

The Smeed's Law parameters  $\alpha$  and  $\beta$  have been re-estimated for this update of the mortality projections using a dataset of crude death rates (total road injury deaths per 100,000 population) drawn from the GHE2016 estimates for 186 countries for years 2000-2016 plus death registration data for

country-years before 2000 from the WHO Mortality Database. In all, there were 3,890 observations for 187 countries, with 1,953 of these being observations for 53 high income countries.

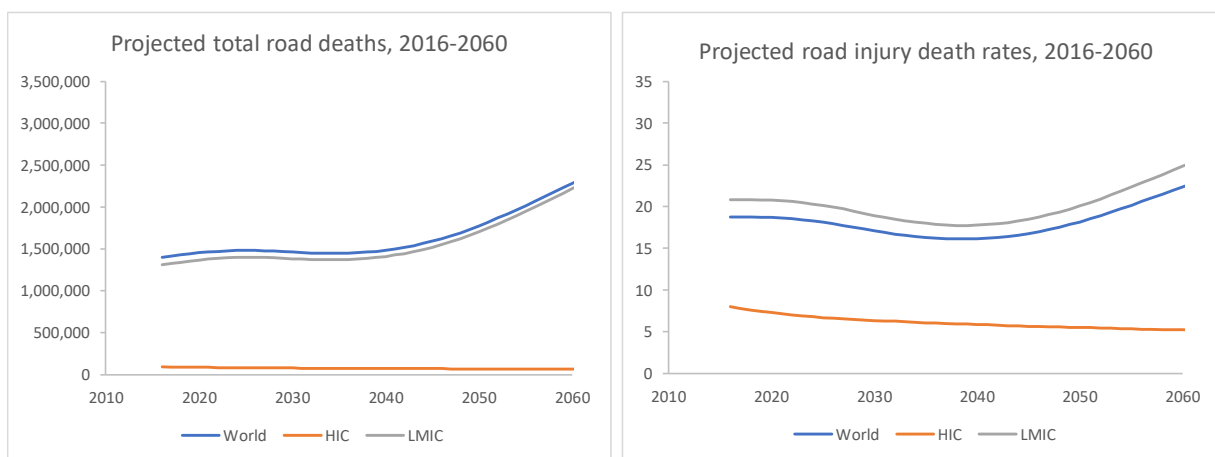
A number of models were fitted involving various regional fixed effects, but these did not result in substantial differences in projected mortality rates, so the parameters from the simplest model fitted to all the data were used (with a fixed effect for WHO Mortality Database as source, to account for any systematic adjustments made in preparing GHE2016 estimates). This model gave  $\alpha = 332$  and  $\beta = 5.5$ , resulting in a fatality rate turning point at 182 vehicles per 1000 population.

To provide a higher rate of decline at high levels of vehicle ownership matching that observed in high income countries in the last decade, a time parameter was introduced to Smeed's law as follows:

$$M_{a,k,t} = M_{a,k,0} \times (1 + \tau \times (t - 2016)) \times 332 \times \frac{vpc}{1000} \times \exp\left(-5.5 \times \frac{vpc}{1000}\right)$$

The parameter  $t$  was set at -1.81 so that the projected overall death rate for the high income countries would match the overall death rate in 2016 if the country-level average annual rates of change observed over the period 2007-2016 were projected to continue unchanged. The following figure shows the resulting trends in road injury crude deaths rates and total deaths for high income countries, low- and middle-income countries, and all countries combined.

*Figure 6 Projected trends in road injury mortality, world and high income (HIC) and low- and middle-income (LMIC) countries, 2016-2060.*



These business-as-usual projections assume that rates of decline in high-vehicle ownership countries will remain similar to those observed in high income countries currently. Potential changes in vehicle technology and road safety, as well as responses to global warming and sustainability, are not factored into the business-as-usual scenario, and this is a cause of death where business-as-usual is quite unlikely to be the most probable future.

## 4.8 Homicide

For the WHO Global status report on violence prevention 2014 (46) an ensemble of five regression models was used to estimate levels for countries without data and to fill time series gaps. This ensemble made use of the following five covariates:

- proportion of the population that are 15-30 year old males
- infant mortality rate
- percent of the population living in urban areas
- alcohol drinking pattern
- gender inequality index
- religious fractionalization

We used this ensemble model with regression coefficients from the analysis for the 2014 report, together with projected covariates to estimate projected annual rates of change of total homicide rate at country level. For the first three covariates above we used projections from the World Population Prospects 2017 (7) and the World Urbanization Prospects (47). We assume that alcohol drinking patterns (48) and religious fractionalization (49) remain constant into the future. The gender inequality index (gii) of the UNDP (50) was projected forward using a regression of gii against  $\ln(\text{lagged gdp})$  and indicator variables for region and interaction of region with  $\ln(\text{lagged gdp})$ . Lagged gdp is a weighted average of the last five years of gdp values.

The projected rates of change of homicide death rates from the ensemble model were used to project the baseline death rates forward to 2060 under the business-as-usual scenario. Overall, the global age-standardized homicide rate is projected to decline 19% from 6.4 per 100,000 in 2016 to 5.2 per 100,000 in 2060. Total global homicides rise from 477 thousand in 2016 to 485 thousand in 2030 and 501 thousand in 2060.

## 4.9 Natural disasters

The frequency of occurrence of natural disasters is highly dependent on type of disaster and geographical location and higher magnitude disasters typically follow a power law distribution (51), with rare large disasters dominating global mortality levels (for example, the 2010 Haiti earthquake and the 2004 Asian tsunami were responsible for 91% and 94% of global natural disaster deaths in those years).

The probability of occurrence of a natural disaster was modelled using WHO estimates of deaths due to natural disasters, by type, country and year for the period 1985-2017 (52), based largely on data collected in the EM-DAT/CRED International Disaster Database (53). Disasters were classified into five categories: earthquakes, floods, tsunamis, storms, and drought/heatwave. The INFORM project (54, 55) estimates indicators (on a 0 to 10 scale) for 191 countries for three dimensions of disaster risk: risk of occurrence for the above listed five disaster categories, vulnerability and lack of coping capacity. For each of the five disaster categories, the annual probability of occurrence was modelled using logistic regression with category specific risk and year as covariates and WHO region-level fixed effects. A penalized likelihood method was used to fit the logistic regression, as standard likelihood estimators are biased for rare events (56, 57).

For each of the five types of disasters, the death rate per event was assumed to follow a log-normal distribution whose mean was modelled using the following covariates: disaster risk, vulnerability, lack of coping capacity with WHO region-level fixed effects. Lognormal distribution was assumed rather than a power law, as the power law distribution does not have a defined variance (58).

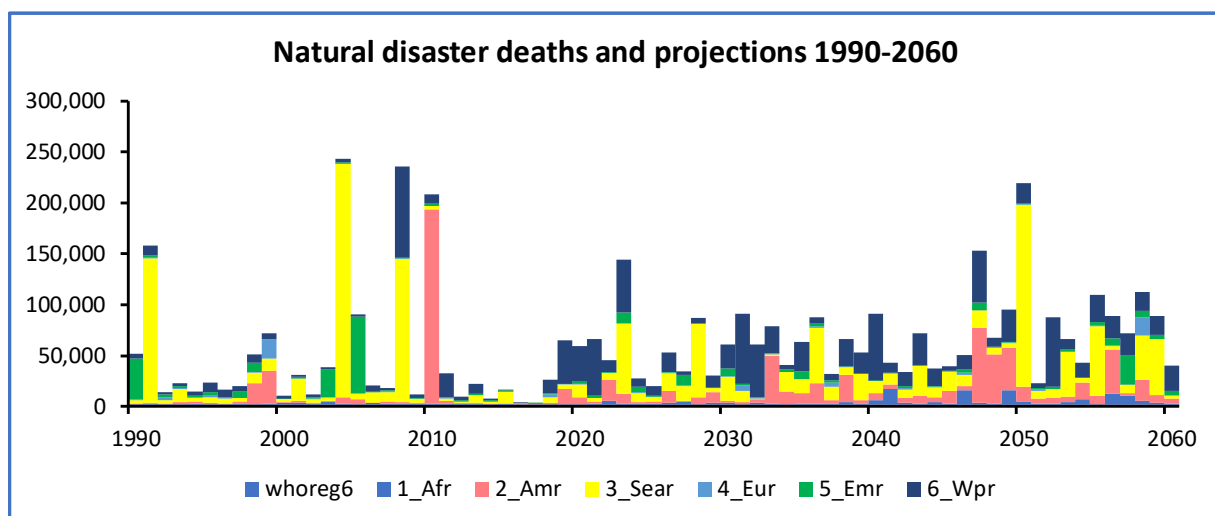
To project disaster deaths by country, the following procedure was carried out for each disaster type:

1. For each country-year, a random draw was taken from a uniform distribution and used to assign occurrence or non-occurrence of disaster based on the predicted country-level probability of occurrence.
2. For each country-year disaster, the mortality rate was taken as a random draw from a log-normal distribution with the regression-estimated country-level mean. Rare extreme outliers were adjusted to avoid occasional super-disasters beyond maximum observed levels.
3. Five independent sets of projected estimates were averaged at country-year level.

Time covariates were included in some of the regression analyses and they resulted in an overall 1% per annum growth rate in the global natural disaster death rate and 2% annual growth in total number of deaths. While some types of disasters such as tropical storms, floods, drought and heatwave are predicted in increase in frequency and severity with global warming, these projections have not explicitly attempted to take this into account. It is also quite possible that continued economic growth and risk mitigation activities may reduce vulnerability and increase the ability of countries to cope. So these projections should be taken as no more than an indicative business-as-usual projection that does not take account of potential future changes in disaster risk and response. Additionally, unlike for other causes, the stochastic nature of the disaster projections means that they will change every time they are run, and so should NOT be taken as any more than broadly indicative at regional level.

The following figure summarizes the projected global deaths for natural disasters by year and WHO region.

*Figure 7 Historical levels and stochastic projection of natural disaster deaths by WHO Region, 1990-2060*





#### 4.10 Collective violence

Unlike natural disasters, conflicts are not always discrete events localized within a short time period. However, for the purposes of projection, duration of conflict was ignored and conflict occurrence was modelled independently for each year. WHO estimates of deaths due to conflicts (organized violence including wars, communal conflict, non-state actors, genocide and terrorism) for the period 1989-2017 were used to model the probability of non-zero conflict deaths using penalized likelihood logistic regression (56, 57) with regional fixed effects and the following covariates: the EIU democracy index (59), the PTS Political Terror Scale (60), Worldwide Governance Indicators (WGI) for political stability and absence of violence (pve) and for government effectiveness (gee) (61, 62), the INFORM indicator for conflict risk (54, 55), log of GDP per capita, average ethnolinguistic fractionalization (63) religious fractionalization and language fractionalization (49). For the business as usual projections, covariate values for 2016 were assumed to remain constant into the future.

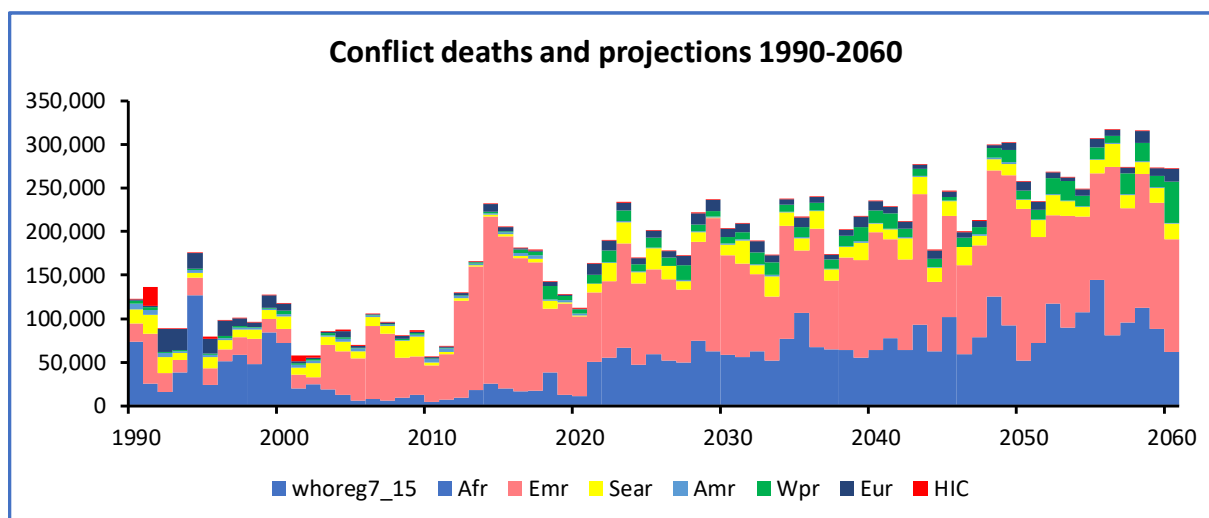
The death rate per conflict event was assumed to follow a log-normal distribution whose mean was modelled using the following covariates: with regional fixed effects and the following covariates: the EIU democracy index (59), the PTS Political Terror Scale (60), Worldwide Governance Indicators (WGI) for political stability and absence of violence (pve) and for control of corruption (cce) (61, 62), the INFORM indicators for conflict risk and current conflict intensity (54, 55), young men aged 15-29 as per cent of total population (7), average ethnolinguistic fractionalization (63) and language fractionalization (49).

To project conflict deaths by country, the following procedure was carried out for each disaster type:

1. For each country-year, a random draw was taken from a uniform distribution and used to assign occurrence or non-occurrence of conflict based on the predicted country-level probability of occurrence.
2. For each country-year conflict, the mortality rate was taken as a random draw from a log-normal distribution with the regression-estimated country-level predicted mean. Extreme outliers were censored to avoid occasional very large estimates.

The conflict projections involve a set of random draws at country level, and should not be taken as more than a broadly indicative at regional level under a business as usual scenario in which current overall global conflict death rates remain broadly similar into the future. The following figure summarizes the projected global deaths for natural disasters by decade, disaster type and WHO region.

Figure 8 Historical levels and stochastic projection of conflict deaths by WHO Region, 1990-2060



## 5. Overview of results

Projected global deaths in 2030 and 2060 under the business-as-usual scenario are 68.2 million and 101.8 million respectively. Projected global deaths in 2030 under the UN medium variant projections are 2% higher in 2030 at 69.5 million and 0.7% lower at 101.1 million in (see Figure 9) . Our global projections for all-cause mortality are remarkably close to the UN projections given that our projections are the sum of independent projections for 20 separate cause groups, whereas the UN projections are based on estimated trends in all-cause mortality and fertility. Figure 9 also shows the projected numbers of deaths for the three major cause groups: Group 1 (infectious diseases, maternal, neonatal and nutritional causes), Group 2 – noncommunicable diseases, and Group 3 – injuries.

*Figure 9 Comparison of projected global deaths with UN WPP2017 projections, 2016-2060*

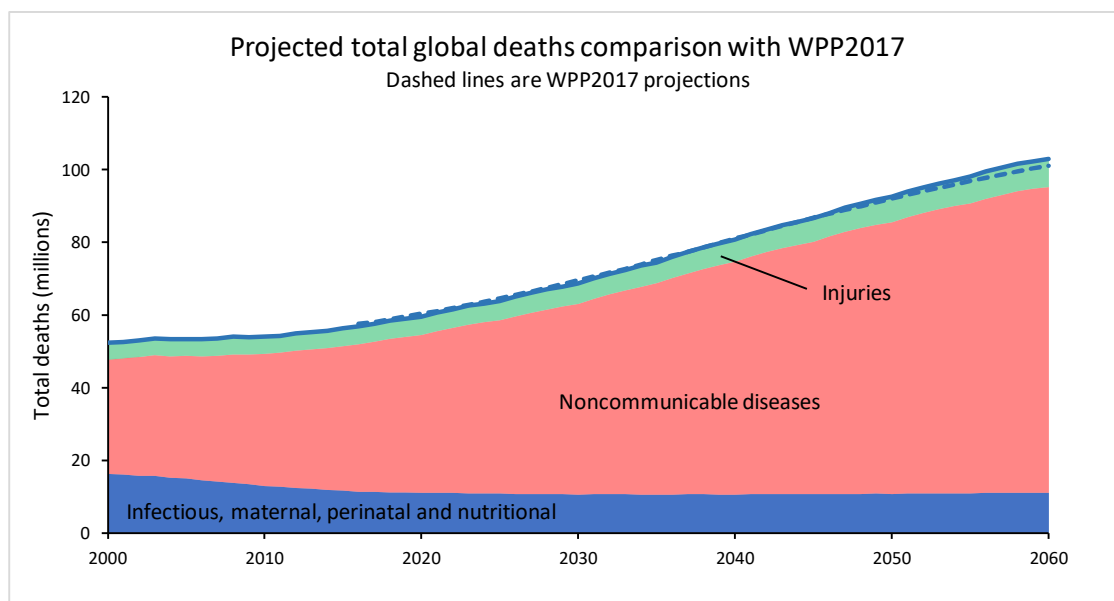


Figure 10 Comparison of projected deaths with UN WPP2017 projections, by WHO Region, 2016-2060

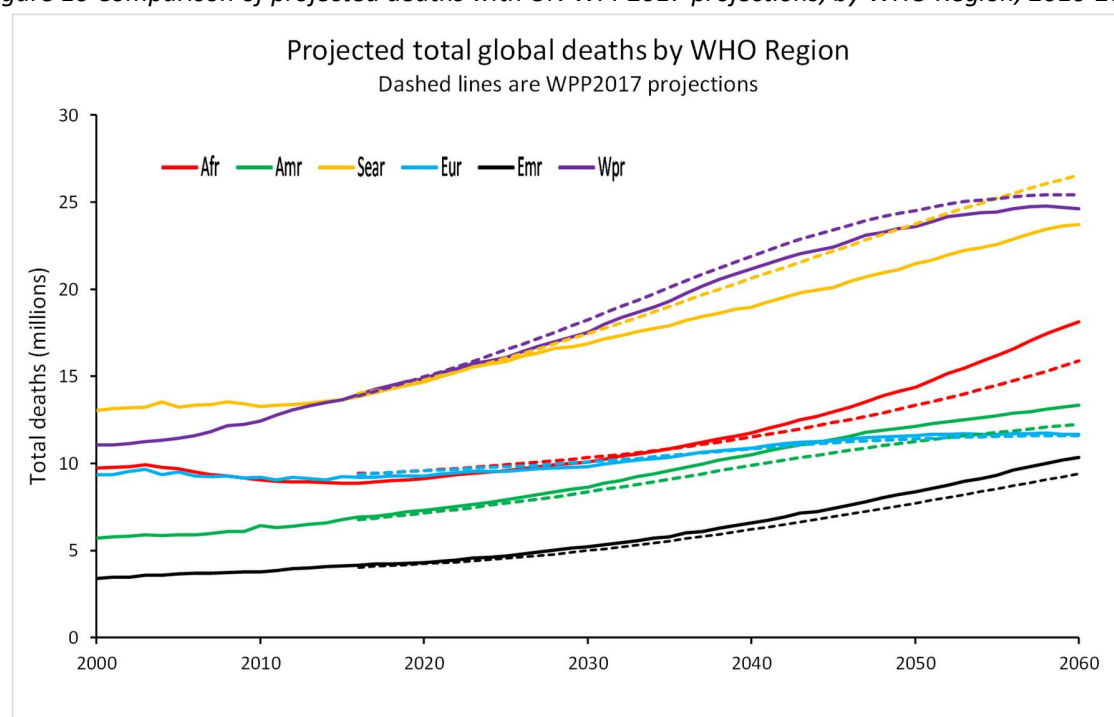
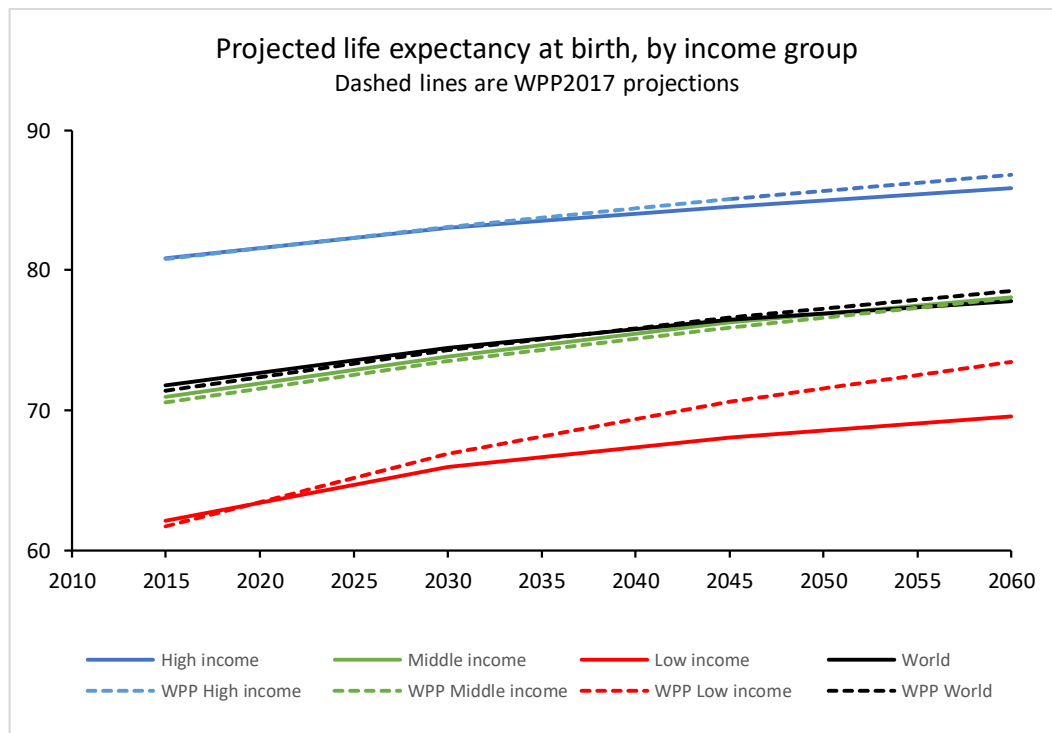


Figure 10 compares projected total deaths by WHO region with the UN WPP2017 projections. The results are very similar for all regions except the South East Asian Region and the African Region. For the South East Asian Region, the UN projections are higher, with 3.5% more deaths in 2030 rising to 12% more deaths in 2060. For the African Region, the UN projections are slightly higher in 2030 but by 2060 are 12% lower.

Figure 11 compares projected life expectancies at birth for the world and for WHO income groups. The projections are very similar for the world and for middle- and high-income countries. The main difference is for low income countries (predominantly African) where the WHO projected life expectancy is 1 year lower than the UN projected life expectancy in 2030 rising to 3.9 years difference in 2060.

*Figure 11 Comparison of projected life expectancies at birth, by country income group, 2016-2060*



At the global level, the age-standardized death rates for most important causes are falling with time, faster in most cases for Group 1 causes than Group (see figures 12A and 12B). The main exceptions are for diabetes, breast cancer and road injuries. However, for many of these causes, the total projected deaths are rising with time because of population growth and ageing. Only the relatively fast declining Group 1 causes are likely to also have declining total numbers of deaths (see figures 13A and 13B).

*Figure 12 Projected global age-standardized death rates, selected causes, 2000-2060*

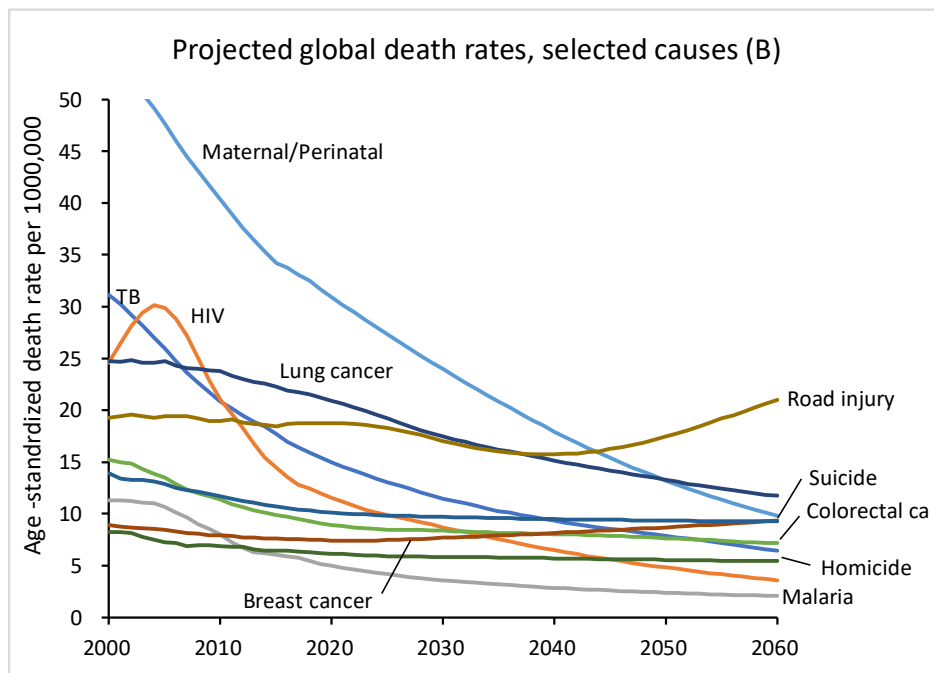
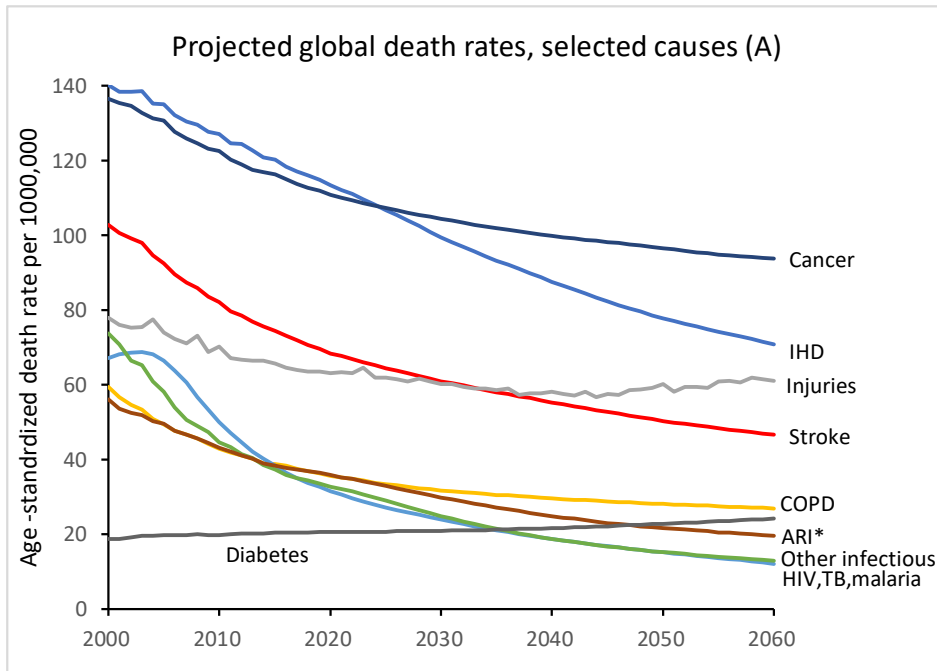
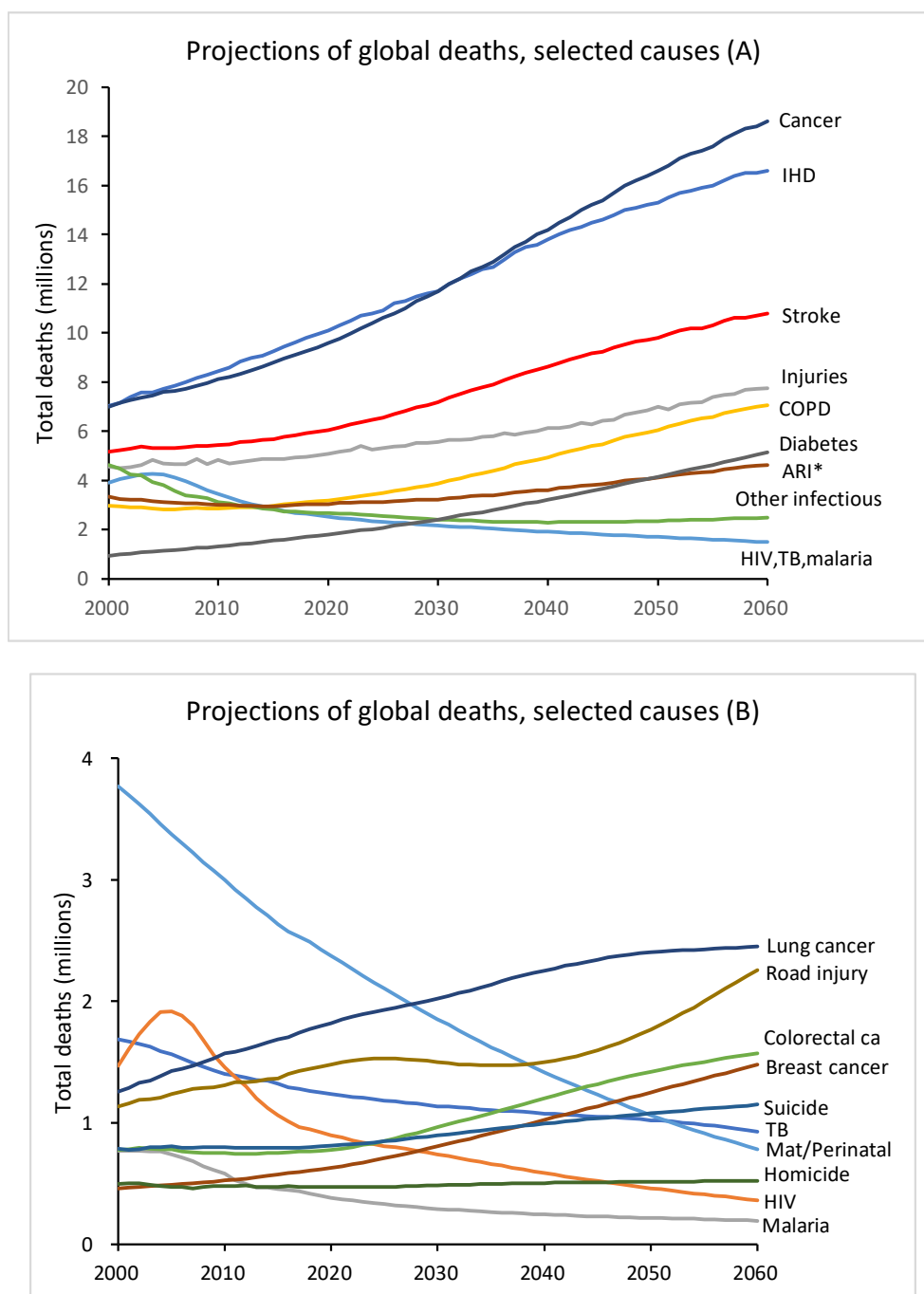


Figure 13 Projected global deaths, selected causes, 2000-2060



The projections of deaths by cause are not intended as forecasts of what will happen in the future but as projections of current and past trends, based on certain explicit assumptions. The methods used base the disease burden projections largely on broad mortality projections driven by projections of future growth in income and increases in human capital in different regions of the world, together with a

model relating these to cause-specific mortality trends based on the historical observations in countries with death registration data over the last 60 years. The results depend strongly on the assumption that future mortality trends in poor countries will have a similar relationship to economic and social development as has occurred in the higher income countries. If governments give increased priority and resources to achievement of the Sustainable Development Goals and progress towards Universal Health Coverage with the most relevant cost-effective interventions, it is entirely possible that future declines in mortality for many causes will be faster than these business-as-usual projections.

Despite these uncertainties, projections provide a useful perspective on sustainable health trends and health policies, provided that they are interpreted with a degree of caution. Projections enable us to appreciate better the implications for health and health policy of currently observed trends, and the likely impact of fairly certain future trends, such as the ageing of the population, and the continuation of the epidemiological transition in developing countries. These projections represent one scenario of the future for population health, under an explicit set of assumptions. If the future is not like the past, for example through sustained and additional effort to address the Sustainable Development Goals and progress towards Universal Health Coverage, or through major scientific breakthroughs, then the world may well achieve faster progress than projected under the business-as-usual scenario. On the other hand, if economic growth in low income countries is lower than the forecasts used here, and global warming results in additional adverse impacts on economic and social development, then the world may achieve slower progress and widening of health inequalities.

## Acknowledgements.

This update was prepared by Colin Mathers, with inputs and assistance from Doris Ma Fat, Jessica, Ho, Annette Mahanani, Dan Hogan and Gretchen Stevens. It draws on datasets and analyses carried out by a wider group of WHO staff and collaborators, including Interagency Groups and the MCEE and NCD-RisC academic collaborations. The development of modelling approaches has benefited from discussions with Majid Ezzati, Vasilis Kontis, Margie Peden and Dan Hogan.

## References

1. Global Health Estimates 2016: Deaths by cause, age and sex, by country and by region, 2000-2016. Geneva: World Health Organization; 2018. Available at [http://www.who.int/healthinfo/global\\_burden\\_disease/estimates/en/](http://www.who.int/healthinfo/global_burden_disease/estimates/en/).
2. World Health Organization (2018). Projections of mortality and causes of death, 2017-2060. Available on the WHO website at [http://www.who.int/healthinfo/global\\_burden\\_disease/projections/en/](http://www.who.int/healthinfo/global_burden_disease/projections/en/).
3. Mathers CD, Loncar D. Projections of global mortality and burden of disease from 2002 to 2030. PLoS Medicine, 2006, 3(11): e442.

4. World Health Organization. The global burden of disease: 2004 update. Geneva, World Health Organization, 2008.
5. World Health Organization (2013). Projections of mortality and causes of death, 2012-2030. Available on the WHO website at [http://www.who.int/healthinfo/global\\_burden\\_disease/projections/en/](http://www.who.int/healthinfo/global_burden_disease/projections/en/).
6. Murray CJL, Lopez AD, eds. The global burden of disease: a comprehensive assessment of mortality and disability from diseases, injuries and risk factors in 1990 and projected to 2020. Cambridge, Harvard School of Public Health on behalf of the World Health Organization and the World Bank, 1996.
7. UN Population Division. *World Population Prospects - the 2017 revision*. New York, United Nations, 2017.
8. Peto R, Lopez AD, Boreham J, Thun M, Heath JC (1992) Mortality from tobacco in developed countries: indirect estimation from National Vital Statistics. *Lancet* 339: 1268-1278.
9. World Bank (2018). International Comparison Program Database: GDP per capita, PPP (constant 2011 international \$) 1990-2017. Available at <https://data.worldbank.org/indicator/NY.GDP.PCAP.PP.KDm> (accessed 8 September 2018).
10. OECD (2018). GDP long-term forecast to 2060. <https://data.oecd.org/gdp/gdp-long-term-forecast.htm> (Accessed on 19 August 2018)
11. Hughes BB et al (2017). The International Futures (IFs) modeling system, version 7.31 (September 2017). Frederick S. Pardee Center for International Futures, Josef Korbel School of International Studies, University of Denver, [www.ifs.du.edu](http://www.ifs.du.edu).
12. Price Waterhouse Coopers (2017). The World in 2050. The long view: how will the global economic order change by 2050. Available at <https://www.pwc.com/gx/en/issues/economy/the-world-in-2050.html#data> (accessed 19 August 2018).
13. World Bank (2006). The road to 2050 – sustainable development for the 21<sup>st</sup> century. World Bank: Washington 2006. Available at <http://documents.worldbank.org/curated/en/192421468341095824/pdf/360210rev0The0Road0to0205001PUBLIC1.pdf> (accessed 19 August 2018)
14. World Bank (2018). Oil rents (% gdp), 1960-2016. World Development Indicators Database. Available at <https://data.worldbank.org/indicator/ny.gdp.petr.rt.zs> (accessed 8 September 2018).
15. Barro R, Lee J-W (2018). Barro-Lee Educational Attainment Dataset. Available at [www.barrolee.com](http://www.barrolee.com) (accessed 9 September 2018).
16. Barro R, Lee J-W (2013). A New Data Set of Educational Attainment in the World, 1950-2010." *Journal of Development Economics*, vol 104, pp.184-198.
17. Thun MJ, Carter BD, Feskanich D, et al. 50-year trends in smoking-related mortality in the United States. *The New England journal of medicine* 2013; 368(4): 351-64.
18. Chen Z, Peto R, Zhou M, et al. Contrasting male and female trends in tobacco-attributed mortality in China: evidence from successive nationwide prospective cohort studies. *Lancet* 2015;386(10002):1447-1456. doi:10.1016/S0140-6736(15)00340-2.



19. WHO global report on trends in prevalence of tobacco smoking 2000-2025, second edition. Geneva: World Health Organization; 2018.
20. Institute for Health Metrics and Evaluation (2017). Global Burden of Disease Study 2016 (GBD 2016) Covariates 1980-2016. Seattle, United States: Institute for Health Metrics and Evaluation (IHME), 2017.
21. Euromonitor International. Tobacco industry market research. <http://www.euromonitor.com/tobacco>
22. Institute for Health Metrics and Evaluation (2010). Estimated cigarettes per capita, by sex, for years 1970-2005. Available on the IHME website at <http://www.healthdata.org/>
23. WHO Mortality Database. Geneva: World Health Organization ([http://www.who.int/healthinfo/mortality\\_data/en/](http://www.who.int/healthinfo/mortality_data/en/))
24. WHO methods and data sources for country-level causes of death 2000-2016. Global Health Estimates Technical Paper WHO/HIS/IER/GHE/2018.2. Geneva: World Health Organization; 2018. Available at [http://terrance.who.int/mediacentre/data/ghe/GlobalCOD\\_method\\_2000\\_2016.pdf?ua=1](http://terrance.who.int/mediacentre/data/ghe/GlobalCOD_method_2000_2016.pdf?ua=1)
25. World Health Organization. Global Tuberculosis Report 2017. Geneva, WHO, 2017.
26. Uplekar M, Weil D, Lonnroth K, Jaramillo E, Lienhardt C, Dias HM, et al. WHO's new End TB Strategy. *Lancet*. 2015;385(9979):1799–1801.
27. World Health Organization. The End TB Strategy [webpage]. Available at <http://www.who.int/tb/strategy/end-tb/en/> (accessed 6 October 2018).
28. Arregui S, Iglesias MJ, Samper S, Marinova D, Martin C, Sanz J, Moreno Y. Data-driven model for the assessment of Mycobacterium tuberculosis transmission in evolving demographic structures. *Proc Natl Acad Sci U S A*. 2018 Apr 3; 115(14): E3238–E3245. Published online 2018 Mar 21. doi: 10.1073/pnas.1720606115
29. UNAIDS (2018). UNAIDS Data 2018. Available at <http://www.unaids.org/en/resources/documents/2018/unaids-data-2018> (accessed 12 September 2018)
30. Bhatt S, Weiss DJ, Cameron E et al. The effect of malaria control on Plasmodium falciparum in Africa between 2000 and 2015. *Nature*. 2015; 526: 207-211.
31. Malaria Atlas Project (2018). Updated national estimates of malaria parasite prevalence for years 2000-2017.
32. World Malaria Report 2017. Geneva, World Health Organization, 2017.
33. Trends in maternal mortality: 1990 to 2013. Estimates by WHO, UNICEF, UNFPA, The World Bank and the United Nations Population Division. Available at [http://apps.who.int/iris/bitstream/handle/10665/112682/9789241507226\\_eng.pdf?sequence=2](http://apps.who.int/iris/bitstream/handle/10665/112682/9789241507226_eng.pdf?sequence=2) (accessed 12 September 2018)
34. Alkema L, Zhang S, Chou D, Gemmill A, Moller AB, Ma Fat D, Say L, Mathers C, Hogan D. A Bayesian approach to the global estimation of maternal mortality. *Annals of Applied Statistics* 2017, Vol. 11, No. 3, 1245-1274. Available at <https://projecteuclid.org/euclid.aos/1507168829> (accessed 12 September 2018).

35. UNICEF Data: Monitoring the Situation of Children and Women [website]. New York: United Nations Children's Fund; 2015 (<http://data.unicef.org/>).
36. Asia Pacific Cohort Studies Collaboration. Body mass index and risk of diabetes mellitus in the Asia-Pacific region. *Asian Pacific Journal of Clinical Nutrition*, 2006, 15:127-133.
37. Finucane MM; Stevens GA; Cowan MJ; Danaei G; Lin JK; Paciorek CJ; Singh GM; Gutierrez HR; et al. National, regional, and global trends in body-mass index since 1980: systematic analysis of health examination surveys and epidemiological studies with 960 country-years and 9.1 million participants. *Lancet* 2011, 377:557-567.
38. Kontis V, Mathers CD, Rehm J, Stevens GA, Shield KD, Bonita R, Riley LM, Poznyak V, Beaglehole R, Ezzati M. Contribution of six risk factors to achieving the 25x25 non-communicable disease mortality reduction target: a modelling study. *The Lancet*, 2014; DOI: [10.1016/S0140-6736\(14\)60616-4](https://doi.org/10.1016/S0140-6736(14)60616-4).
39. Kopits, E., Cropper, M. (2005): Traffic fatalities and economic growth, *Accident Analysis and Prevention*. Vol. 37, Issue 1 January 2005, pp.169-178.
40. Smeed, R.J. (1949): Some statistical aspects of road safety research, *Journal of Royal Statistical Society, Series A (General)*, Vol. 112, No. 1, 1949, pp. 1-34.
41. International Road Federation (2009). IRF World Road Statistics 2009. Data 2002-2007. IRF: Geneva. <https://worldroadstatistics.org/>
42. World Health Organization (2013) Global status report on road safety 2013. Geneva, World Health Organization.
43. World Health Organization (2015). Global status report on road safety 2015. Geneva, World Health Organization.
44. Dargay, J., Gately, D. and Sommer, M. (2007) Vehicle Ownership and Income Growth, Worldwide: 1960-2030. *Energy Journal*. 2007, vol. Volume 28, issue Number 4, 143-170.
45. Koren, Csaba & Borsos, Attila. (2010). Is Smeed's law still valid? A world-wide analysis of the trend in fatality rates. *Journal of Society For Transportation and Traffic Studies (JSTS)*. 1. 64-76.
46. Global status report on violence prevention 2014. Geneva, World Health Organization; 2014.
47. UN Population Division. World Urbanization Prospects: 2014 Revision. New York, United Nations, 2014.
48. Global status report on alcohol and health 2014. Geneva, World Health Organization; 2014.
49. Alesina A, Devleeschauwer A, Easterly W, Kurlat S, Wacziarg R. Fractionalization. *Journal of Economic Growth* 2003, 8: 155-94.
50. United Nations Development Program. Human Development Report 2016. New York, UNDP. Available at [http://hdr.undp.org/sites/default/files/2016\\_human\\_development\\_report.pdf](http://hdr.undp.org/sites/default/files/2016_human_development_report.pdf) (accessed 12 September 2018)
51. Becerra, Oscar & Johnson, Neil & Meier, Patrick & Restrepo, Jorge & Spagat, Michael. (2006). Natural Disasters, Casualties and Power Laws: A Comparative Analysis with Armed Conflict. Paper prepared for presentation at the 2006 Annual Meeting of the American Political Science Association (APSA), Philadelphia,

- PA, August 31-September 3, 2006. Available from:  
[https://www.researchgate.net/publication/228576670\\_Natural\\_Disasters\\_Casualties\\_and\\_Power\\_Laws\\_A\\_Comparative\\_Analysis\\_with\\_Armed\\_Conflict](https://www.researchgate.net/publication/228576670_Natural_Disasters_Casualties_and_Power_Laws_A_Comparative_Analysis_with_Armed_Conflict) [accessed Sep 20 2018].
52. WHO methods and data sources for country-level causes of death 2000-2016 (Global Health Estimates Technical Paper WHO/HIS/IER/GHE/2018.3).
  53. CRED. EM-DAT: The CRED International Disaster Database. Belgium, Université Catholique de Louvain, 2017.
  54. Inter-Agency Standing Committee Reference Group on Risk, Early Warning and Preparedness. INFORM 2019 Index for Risk Management (release: 3 September 2018 v 0.3.5). Available at <http://www.inform-index.org/> (accessed 20 September 2018)
  55. Marin-Ferrer, M., Vernaccini, L. and Poljansek, K., Index for Risk Management INFORM Concept and Methodology Report — Version 2017, EUR 28655 EN, doi:10.2760/094023
  56. Gary King and Langche Zeng. "Logistic Regression in Rare Events Data." Political Analysis 9 (2001): 137-163.
  57. Firth D. Bias reduction of maximum likelihood estimates. Biometrika 1993, 80(1), pp. 27-38, <https://doi.org/10.1093/biomet/80.1.27>
  58. Blackwell, Calvin. (2012). Investigating Power Laws in Hurricane Damages. SSRN Electronic Journal. 10.2139/ssrn.2192074.
  59. The Economist Intelligence Unit (2017). Democracy Index 2007-2017. Democracy Index 2017: Free Speech under Attack. pp13-17. Available at [https://pages.eiu.com/rs/753-RIQ-438/images/Democracy\\_Index\\_2017.pdf](https://pages.eiu.com/rs/753-RIQ-438/images/Democracy_Index_2017.pdf) (accessed 20 September 2018).
  60. Gibney, Mark, Linda Cornett, Reed Wood, Peter Haschke, Daniel Arnon, and Attilio Pisanò. 2017. The Political Terror Scale 1976-2016. Date Retrieved, from the Political Terror Scale website: <http://www.politicalterrorscale.org/> (accessed 21 September 2018)
  61. Kaufmann D, Kraay A, Mastruzzi M (2010). "The Worldwide Governance Indicators : A Summary of Methodology, Data and Analytical Issues". World Bank Policy Research Working Paper No. 5430, [http://papers.ssrn.com/sol3/papers.cfm?abstract\\_id=1682130](http://papers.ssrn.com/sol3/papers.cfm?abstract_id=1682130)
  62. Kaufmann D, Kraay A. The Worldwide Governance Indicators, 2018 Update for 1996-2017. Available at <http://info.worldbank.org/governance/wgi/#home> (accessed 21 September 2018).55
  63. La Porta R, et al. The quality of government. Journal of Law, Economics and Organization. 1999, 15(1), pp222-279.