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Disease and demography: A Systems-dynamic cohort-component population model to assess the implications of disease-specific mortality targets

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Abstract

Introduction: The 2015 Sustainable Development Goals include the objective of reducing mortality from noncommunicable diseases by 25 percent. Accomplishing this objective has demographic implications with relevance for countries' health systems and costs. However, evidence on the system-wide implications of NCD targets is limited.

Methods: We developed a cohort-component model to estimate demographic change based on user-defined disease-specific mortality trends. The model accounts for aging over 101 annual age cohorts, disaggregated by sex, and projects changes in the size and structure of the population based on changes in the trajectories of disease-specific mortality. We simulated alternative demographic outlooks for Bangladesh for 2015-2030 using three mortality scenarios. The 'status quo' scenario entails that the disease-specific mortality profile observed in 2015 applies throughout 2015-2030. The 'trend' scenario adopts age-, sex- and disease-specific mortality trajectories projected by WHO for the region. The 'target' scenario entails a 25% relative reduction in mortality from cardiovascular diseases, cancer, diabetes, and chronic respiratory diseases during 2015-2030.

Results: The status quo, trend, and target scenarios project 178.9, 179.6, and 180.1 million population in 2030, respectively. The cumulative number of deaths during 2015–2030 is 17.4, 16.3, and 15.7 million for each scenario, respectively. Over the 15-year period, the target scenario would avert a cumulative 1.64 million and 596 thousand all-cause deaths compared to the status quo and trend scenarios, respectively. Male life expectancy is estimated to increase from 71.1 to 73.2 years in the trend scenario and to 74.4 years in the target scenario. Female life expectancy is estimated to increase from 73.7 to 75.1 years and 76.8 years in the trend and target scenarios, respectively.

Conclusion: The model describes the demographic implications of NCD prevention and control targets. The results can be used to inform future health system needs and support planning for increased healthcare coverage in countries.

Key Words: cohort component model; system dynamics; population projection; Bangladesh; noncommunicable diseases (NCDs); Sustainable Development Goals targets; demography; mortality, fertility, net migration.

Strengths and Limitations of the Study

- The model provides an understanding of how changes in disease-specific mortality may contribute to the demographic outlook of countries by simulating demographic evolution paths corresponding to pre-specified mortality outlooks.
- The model has the capability to produce consistent and comparable cross-country estimates for a set of demographic indicators that are easy to update using country data across multiple countries.
- The results provide demographic information needed to plan for services to meet future demands of different segments of the population.
- The cohort component method does not explicitly incorporate socio-economic determinants of population change.
- The model outcomes are based on conditional calculations producing outlooks for a set of demographic indicators under a particular set of reasonable assumptions.

Introduction

Changes in population size and demographic composition have broad economic and social implications. Informed decisions regarding population-level policies and interventions hinge on robust population projections that delineate the dynamic interplay of demographic processes such as fertility, mortality and migration. Generating counts for population cohorts of interest determines investment in sectors like health, education, infrastructure, and others.[1, 2]

We present a cohort-component population projection model to assess demographic changes associated with changes in the distribution of causes of death. Current population projections reflect a variety of assumptions about fertility, mortality, and migration.[3-6] For instance, the UN produces eight variants of population projections, five of which are based on different trajectories of fertility, while assumptions regarding mortality are determined by probabilistic trends of life expectancy at birth, and international migration is assumed either constant or zero.[3] The existing population projection models typically emphasize the role of fertility but do not provide an understanding of how changes in disease-specific mortality may contribute to the demographic outlook of countries.

Preventable deaths and disability caused by communicable diseases, maternal, perinatal and nutritional conditions (CMPN), noncommunicable diseases (NCDs), and injuries constitute core concerns across nations. Among these, cardiovascular diseases (CVDs) are in the lead, accounting for 15.2 million deaths of all 56.9 million deaths worldwide in 2016.[7] Given the rising significance of NCDs in global health, the 2030 Sustainable Development Goals (SDGs) aim to reduce overall mortality from the four major NCDs (CVDs, diabetes, cancer, and respiratory diseases) by 25% by 2030.[8,9] These objectives occur in the context of many budgetary and planning constraints that affect low-income and middle-income countries (LMICs). Further, variations in the incidence and prevalence of diseases across sex and age cohorts require policymakers to formulate targeted interventions and policies. Understanding the evolution of different age-cohorts resulting from shifts in disease-specific mortality over time can inform the resource needs for national scale-up of interventions to attain SDG health targets.

The dynamic population projection model in this study simulates a range of demographic evolution paths corresponding to pre-specified disease-specific mortality outlooks. The results provide demographic information needed to plan for services to meet future demands of different segments of the population. Although the model in this study is applied to Bangladesh, it is replicable across different countries, and can serve as a tool for planners to simulate user-defined scenarios corresponding to assumed fertility, mortality, and international migration trajectories.

Over the last several decades, Bangladesh has made substantial progress in disease prevention and control of childhood communicable diseases, but NCDs have emerged as the primary cause of death and disability in the country.[10,11] In response, the Government of Bangladesh (GoB) has formulated an NCD action plan to reduce NCDs and associated risk factors through a multisectoral coordinated approach[12]. Bangladesh NCD prevention and control targets are consistent with the 2030 SDGs and with the WHO South-East Asia regional NCD 2025 objectives of reducing by 25% premature mortality from CVDs, diabetes, respiratory diseases, and cancer.[12,13] Attainment of these targets entail population-level prevention and treatment initiatives. A first step in planning for such initiatives is information on the demographic outcomes associated with accomplishing the health objectives of these initiatives.[14] To this end, the present study models the demographic outlook for Bangladesh from 2015 to 2030 under the assumption of attaining the 2030 SDG target of reducing mortality from four major NCDs by 25%.

Methods and Data

Patient and Public Involvement

Patients or the public were not involved in the design, or conduct, or reporting, or dissemination plans of this research.

The systems-dynamic cohort-component population model

A cohort-component population projection model tracks each sex- and age-specific cohort of people throughout its lifetime, subject to assumed age- and sex-specific mortality, fertility, and migration.[6,15] The model represents a "systems" structure defined by the stocks and flows and the connections between them.[16-19] In this model, the population in each year is the stock variable, while births, deaths, and international migration represent the flows. The model starts with defining the initial-year population, disaggregated by sex- and age-cohorts, followed by defining the fertility, mortality, and migration attributes of each cohort throughout the projected horizon. In other words, the model in this study resembles an aging chain where, after birth, each birth cohort progresses from childhood (first stock) to old age (last stock) unless the individual dies and leaves the system.

Figure 1 presents an overview of the model structure using a stock-and-flow diagram. The population's dynamic path begins with the initial population stock observed in 2015 for Bangladesh, disaggregated by sex and age. In each subsequent year, changes in the annual population stock occur through adding births, subtracting deaths, and through net international migration (emigration minus immigration). The number of annual births is determined by applying exogenously set age-specific fertility rates to the cohorts of reproductive-age women (age 15-49). In each year, people in each age cohort leave the system due to deaths and international migration. The causes of deaths are aggregated into six major types of disease categories: communicable, maternal, perinatal and nutritional conditions (CMPN); neoplasms; diabetes; cardiovascular diseases; respiratory diseases; other NCDs and injuries. The Supplementary Table S1 maps these broad categories with the disaggregated WHO Global Health Estimates (GHE) causes of death codes.[20] Sex, age-group and disease specific deaths rates determine the number of deaths each year. Sex and age specific net migration rates determine the number of people removed from the population due to migration to other countries.

[Figure 1 here]

The model allows the option of simulating different scenarios by setting sex- and age-specific fertility rates; sex-, age-, and disease-specific death rates; and net-migration rates, for each year over the analytic time-horizon (2015 – 2030). For instance, scenarios of different mortality trends could reflect status-quo (i.e. constant death rates over time), trajectories based on historical trends, trajectories based on the predicted impact of disease prevention interventions or reductions in risk factor exposures informed by the literature, or user-defined mortality outlooks based on national plans.

Table 1 describes the model structure by outlining the variables, parameters, and equations. The model generates population counts for 202 annual age-sex cohorts consisting of age 0 – 100+ years for male and female, respectively. Data on fertility, mortality, and net-migration rates were only available by age-group and were assigned to corresponding annual cohorts within each age-group. We used two age-groups depending on data availability, separately for male and female: (1) six broad age-groups: age 0–4, age 4–14, age 15–29, age 30–49, Age 50–69, Age 70 and above;

(2) five-year age-groups: age 0–4, age 5–9, age 10–14, age 15–19, age 20–24, age 25–29, age 30–34, age 35–39, age 40–44, age 45–49, age 50–54, age 55–59, age 60–64, age 65 and above.

[Table 1 here]

Demographic Indicators

The model produces several key demographic indicators, including population counts and age structure; total, child, and old-age dependency ratios; the number of births; crude birth rate; total fertility; net reproduction rate; the rate of natural population increase; the number of deaths by diseases; infant and child mortality rates; crude death rate; life expectancy at birth and at each age; the probabilities of dying between age 0 to 70 and between 15 and 70; and total years of lives lost and by diseases. The Supplementary Table S2 provides brief definitions of the indicators.[21]

Bangladesh case study: demographic implications of SDG NCD mortality targets

Baseline Data

To initiate the population dynamics, we needed base year population, age-specific fertility rates, age-specific death rates, and age-specific net migration rates. We used the 2015 annual cohort (age 0-100) population data from the UN population projection (medium variant); age-specific fertility rates reported by Bangladesh Bureau of Statistics; age-specific total death rates are obtained from the UN Life tables for Bangladesh for the year 2015; and age-specific net migration rates from Bangladesh Bureau of Statistics.[3,22,23,24] The UN estimate of the ratio of sex at birth for Bangladesh is 1.05 for their entire analytic horizon; we used the same for this model.[24] The UN lifetable for Bangladesh assumes 100% mortality rate for ages 85 and above.[24,25] Our model assumed that all people in the last age cohort (100+ years) leave the system (i.e. die) with 100% mortality rate, with interpolated death rates for ages 85 – 99. The total net migration rate reported in the UN population projection is -2.3/1,000 population; our model assumed the same statistic when applying age-specific net migration rates to the baseline (2015) population.[24] We used WHO GHE disease burden (mortality) data by cause, age, and sex[7] to decompose the total death rates by six broad categories of diseases, so that, $\delta_{s,A,d,t=2015} = \frac{GHE\ Death_{S,A,d,t=2015}}{\sum_{d=1}^{6} GHE\ Deaths_{S,A,d,t=2015}}$

$$d = \{cmpn, cvd, rsp, npl, dbt, othNCDs\}$$

$$\sum_{d=1}^{6} \delta_{s,A,d,t} = \delta_{s,A,t}$$

Where $\delta_{s,A,t}$ (i.e. sex- and age-specific death rates at year *t*) is the sum of death rates from 6 broad categories of diseases (*d*). The Supplementary Table S3 reports the 2015 baseline data used in the model.

Scenarios

We compared three demographic outlooks for Bangladesh: status quo, trend, and target. The three scenarios differ in terms of their assumed mortality trajectories, keeping fertility and net migration trajectories the same across scenarios. The UN population projection uses five fertility variants: low, medium, high, constant-fertility and instant-replacement-fertility. For instance, for Bangladesh, during 2015-2020 the total fertility rates are assumed to be 2.2, 2.05, and 1.68 for the high, medium, and low variants, respectively. For the 2025-2030 period the total fertility rates are assumed to be 2.26, 1.82, and 1.42 for the high, medium, and low variants, respectively.[3, 22] We use the 2015 age-specific fertility rates reported by the Bangladesh Bureau of Statistics (BBS), setting the total fertility rate at 2.10. Then, using the UN probabilistic projections for age-specific fertility rates for the 2025-2030 period, we scaled down the respective 2015 age-specific fertility rates to arrive at a total fertility rate of 1.82 by 2030. For the interim years, the model uses interpolated linear trends. We used the 2015 sex- and age-specific net migration rates obtained from BBS, which remains constant during the 2015-2030 period.[22,23]

The study uses three variants of mortality trajectories. The 'status quo' scenario entails that the 2015 disease-specific mortality rates remain constant for the analysis horizon, so that $I^{\delta}_{s,A,t}$= 1 for the 2015-2030 period. The 'trend' scenario adopts sex, age-group and disease-specific mortality rate trajectories based on the latest WHO GHE regional mortality projections for 2016-2030 for Southern Asia, consisting of Bangladesh and other neighboring countries.[26,27] We estimated the death rates by sex, age-groups, and six broad disease categories for 2016 and 2030 from the number of deaths and total population obtained from GBD study; and then produced a matrix of scale factors such that:

$$I^{\delta}_{s,A,t=2030} = \frac{\delta^{GBD}_{S,A,d,t=2016}}{\delta^{GBD}_{S,A,d,t=2030}}.$$

We used $I^{\delta}_{s,A,t\,=\,2030}$ as the scale factors for our analytic horizon; i.e. $I^{\delta}_{s,A,t\,=\,2030}$ are used to scale the 2030 death rates relative to 2015. The interim years use interpolated mortality rate values. For instance, the GBD study projects that by 2030, the death rates of infectious, maternal, perinatal, and nutritional conditions would reduce by 21% for females aged 70 and above and 48% for males aged 15-29 years. Accordingly, we set the death rate trajectories for the corresponding cohorts to reflect 21% and 48% reductions in 2030 from 2015, respectively. Similarly, depending on sex and age-groups, the reductions of death rates ranges from 3.4% to 22.9% for CVDs; 9.3% to 22.9% for respiratory diseases; and 3.9% to 14.1% for other NCDs and injuries. The GBD study trend projections for neoplasms ranges from 9.3% to 22.9% increases in the death rates by 2030. The changes in diabetes death rates ranges from a reduction of 20.7% to an increase of 3.4%. The Supplementary Table S4 reports all sex, age-group, and disease specific scale factors ($I^{\delta}_{s,A,t}$).

The third scenario is the 'target' scenario, which entails a 25% relative reduction in the overall mortality from cardiovascular diseases, cancer, diabetes, and chronic respiratory diseases between 2015 and 2030. For the other two disease categories (i.e. communicable, maternal, perinatal, nutritional condition; and other noncommunicable diseases and injuries) we use the same mortality trajectories as in the 'trend' scenario. The mortality trajectory for the four major NCDs follows the trend scenario until 2020, and then declines until 2030 to arrive at death rates that are 25% of the corresponding 2015 death rates; i.e. $I^{\delta}_{s,A,t}$=0.75 for 2030 and the interim years use interpolated values. The Supplementary Table S4 reports the $I^{\delta}_{s,A,t}$ values under the target scenarios; the scale factors for 2020 are same in the trend and target scenarios but set at 0.75 for 2030 in the target scenario. The interim years use interpolated values.

Results

Population outlooks

The status quo, trend, and target scenarios project 178.9, 179.6, and 180.1 million population in 2030, respectively. Figure 2 shows the projections for total population along with the three main flow variables in the model, i.e. total births, total deaths, and total net international migration. Given that all fertility and migration assumptions are the same across all three scenarios, differences in the projected population numbers between scenarios reflect differences in the death rate trajectories. The assumption of a steady decline in total fertility from 2.10 in 2015 to

1.82 in 2030 leads to a declining trajectory for the annual number of births from 2.95 million in 2015 to 2.68 million in 2030. The assumed constant age-specific net migration rate kept the total number of people migrating abroad between 356 and 365 thousand each year. However, the annual number of deaths is much higher in the status quo scenario compared to the trend and target scenarios. The model projects 1.26, 1.14, and 1.03 million deaths in 2030. The cumulative number of deaths during 2015 – 2030 are 17.4, 16.3, and 15.7 million in the status quo, trend and the target scenario, entailing 1.64 million and 596 thousand deaths averted in the target scenario compared to the status quo and trend scenarios, respectively.

[Figure 2 here]

Figure 3 shows the inverted age-sex pyramid illustrating the distribution of various age groups in Bangladesh in 2015 (left panel) and 2030 (right panel). The population is distributed along the horizontal axis, with males shown on the left and females on the right. The male and female populations are broken down into 5-year age groups represented as horizontal bars along the vertical axis, with the youngest age groups (age 0-4) at the top and the oldest at the bottom (age 65 and above). The shape of the population pyramid gradually evolves during 2015–2030 based on fertility, mortality, and international migration trends. The apparent cone-shaped population pyramid in 2015 appears more symmetric in 2030, consistent with population ageing over the analytic horizon.

[Figure 3 here]

The evolving population structure is also reflected in Figure 4. The rapid reductions in infant and child mortality accompanied by decreasing fertility lead to a continuous reduction in the child dependency ratio (0.45 in 2015 vs. 0.35 in 2030 trend scenario). On the other hand, as the annual cohorts progress through the analytic period, the old-age dependency ratio, after remaining relatively flat during 2015 – 2020, starts to rise beyond 2020 (0.78 in 2015; 0.77 in 2020; and ~0.11 in 2030 for the three scenarios). The total dependency ratio registers a relatively quick decline from 0.52 in 2015 to 0.45 in 2025 and remains at 0.45 until 2030.

[Figure 4 here]

The annual number of births is determined by the age-specific fertility rates and the number of women of reproductive age 15–49 years. The trajectory of the number of women in reproductive age is affected by the number of deaths and international migration for the corresponding cohorts. In figure 5, for the trend and target scenarios, it is evident that the number of women aged 15-19 begins to decline after 2021, and the number of women aged 20-24 declines after 2024. The number of women in all other older age groups increases during 2015 – 2030, with older cohorts showing larger growth.

[Figure 5 here]

Figure 6 presents the projected mortality trajectories by disease categories. The number of deaths from all disease categories increases except the CMPN category. The continuous decline in death rates and a near-flat population trend with a slight decrease in numbers of children and adolescents lead to a reduction in deaths from CMPN in all scenarios. In all scenarios, NCD deaths rise with the rising population; however, the number of deaths is much smaller in the target scenario. The share of CMPN in total deaths declines from 26.0% in 2015 to 15.1%, 11.1%, and 12.8% in 2030 under the status quo, trend, and target scenario, respectively. On the other hand, the contribution of the four major NCDs (CVD, respiratory diseases, diabetes, and neoplasms) in total deaths increases from 54.9% in 2015 to 64.8%, 68.2%, and 63.6% under the status quo, trend, and target, respectively.

[Figure 6 here]

Table 2 shows the number of deaths under the three mortality scenarios and the number of deaths averted under the target scenario compared to the status quo and trend. Of the four major NCDs, CVD is the major killer, followed by neoplasm, respiratory diseases, and diabetes. In 2025, the model projects 400 thousand, 381 thousand, and 352 thousand deaths from CVD under status quo, trend, and target, respectively, which entails 29 thousand and 47 thousand deaths averted under the target scenario compared to trend and status quo scenarios. Over 2015 – 2030, the target scenario would avert a cumulative 546 thousand (281 thousand male and 265 thousand female) CVD deaths and 330 thousand CVD deaths (151 thousand male and 179 thousand female) compared to the status quo and trend scenario, respectively. Under the target scenario, the cumulative (2015- 2030) number of deaths averted from the four major NCDs is projected to be 973 thousand (511 thousand male, 462 thousand female) and 647 thousand (285 thousand male, 362 thousand female), compared to the status quo and trend scenarios, respectively.

[Table 2 here]

The Supplementary Table S5 shows the projections of years of lives lost (YLL) in the three scenarios, and YLL averted in the target scenario compared to status quo and trend. Compared to the status quo mortality trajectories, the attainment of NCD targets would avert a cumulative (2015 – 2030) 10.5 million YYL (i.e. 5.63, 1.69, 0.40, and 2.77 million YLL averted form CVD, respiratory diseases, diabetes, and neoplasm respectively). Compared to the trend mortality trajectories, the attainment of NCD targets would avert a cumulative (2015 – 2030) 7.1 million YYL (i.e. 2.82, 0.27, 0.52, and 3.49 million YLL averted form CVD, respiratory diseases, diabetes, and neoplasm respectively).

Table 3 reports the projections for life expectancy, infant mortality, under-five mortality, and probability of premature deaths (i.e. age 0-70 and age 15 - 70). Male life expectancy at birth increases from 71.10 in 2015 to 73.23 and 74.40 years in 2030 under the trend and target scenario, respectively. Female life expectancy at birth increases from 73.68 years in 2015 to 75.11 and 76.76 in 2030 in the trend and target scenarios. The projections show declining trends for infant and child mortality in both trend and target scenarios. Since the drivers of infant and child mortality are primarily CMPN diseases, the magnitudes of reduction are similar in the trend and target scenarios. Large reductions in the probabilities of premature deaths (i.e. age 0–70 and age 15–70) are projected in both scenarios, and the reduction is much larger in the target scenario. The probability of death for male between age 0–70 decreases from 459 per 1000 people in 2015 to 387 and 348 per 1000 people in 2030 in the trend and target scenarios, respectively.

[Table 3 here]

Discussion

The cohort-component model in this study projects the demographic outlook of a population using a systems-dynamic process determined by interrelationships between population determinants, including those affected by policy actions.[2,16] The strengths of this model are several. First, it is replicable as it uses established principles about the dynamics of population process. Second, it has the capability to produce consistent and comparable cross-country estimates that are easy to update using country data across multiple countries. Third, it can provide focused estimates for target groups of interest because it tracks population outcomes at a highly disaggregated level.

In the same vein, the model can be flexibly adapted to the intended disaggregation schemes (e.g. more aggregate) of population cohorts and disease categories; Finally, the model outcomes can be potentially linked to other dynamic inputs related to health systems, education, the environment, housing and city planning, infrastructure, energy and utility, and alike. The main contribution of the model used in this study is in estimating the expected demographic shifts associated with different disease-specific mortality trajectories. The resulting estimates inform the effects of proposed NCD control targets, linking the number of deaths averted by achieving these targets to demographic shifts in the population.[28]

The model in this study has several limitations. The cohort component method does not explicitly incorporate socio-economic determinants of population change. The evolution of fertility, mortality and migration over time are not endogenously determined; the respective trajectories are set exogenously using informed assumptions. To that effect, the model outcomes are projections based on a set of assumptions about trajectories of mortality, fertility, and migration. The objective is not to make a perfect prediction of the future, but to assess comparative differences in population trajectories resulting from different health policy scenarios, keeping other input assumptions constant. Therefore, the model outcomes should not be interpreted as a perfect forecast but are based on conditional calculations showing what the future population would be if a particular set of reasonable assumptions were to hold true. While the model captures differences in mortality scenarios, it does not capture the extent of disabilities averted from attaining the targets. Also, the scenarios do not consider the mortality implications of recent covid-19 pandemic in Bangladesh.

The model generates the evolution of annual cohorts and population structure during 2015-2030 using demographic indicators for Bangladesh that are consistent with those offered by international agencies.[3,4,5] For instance, while the model replicates the baseline (2015) demographic indicators as reported in UN population projections, the population shares in 2030 for the 0-14, 15-64, and 65 and above years old age-groups in the UN medium variant projections vs the model trend projections compare as follow: 22.9 vs 23.8; 69.7 vs 68.8; and 7.4 vs 7.4, respectively. This model captures dynamic population outflows based on deaths from disaggregated disease categories, allowing comparison between disease-specific mortality scenarios. We estimated that attaining NCD targets in compliance with SDG 2030 goals, people in Bangladesh will live longer by more than 3 years on average (3.3 and 3.1 years for male and female, respectively). Over the 15-year analysis period, a cumulative 1.64 million all-cause deaths (923 thousand male and 716 thousand female) and 596 thousand all cause deaths (266 thousand male and 330 thousand female) would be averted in the NCD target scenario compared to the status quo and trend scenarios, respectively. In the target scenario, the cumulative number of deaths averted from the four major NCDs are projected to be 973 thousand (511 thousand male, 462 thousand female) and 647 thousand (285 thousand male, 362 thousand female), compared to the status quo and trend scenarios, respectively. These estimates inform the potential benefits as well as trade-offs in health and demographic outcomes associated with accomplishing current NCD targets.

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Table 1: Variables, Parameters, and Equations

Variables	
$P_{s,A,t}$ $s = \{f,m\}$ $A = \{0,1,2,.....100\}$ $t = \{0,1,2,...T\}$	Population ▪ By sex: female (f) and male (m) ▪ By annual age cohorts (age 0 – age 100) ▪ Over time (years: 2015 – 2030)
B_t	Births over time
$B_{s,t}$	Births by sex and over time
$B_{A^*,t}$	Births by age of mother and over time
$D_{s,A,d,t}$ $d = \{cmpn, cvd, rsp, npl, dbt, othNCDs\}$	Mortality from six broad category of diseases *(d)*: ▪ *cmpn:* Communicable, maternal, perinatal, nutritional ▪ *cvd:* Cardiovascular diseases ▪ *rsp:* Respiratory diseases ▪ *npl*: Neoplasms ▪ *dbt:* Diabetes ▪ *othNCDs*: Other noncommunicable diseases and Injuries
$NM_{s,A,t}$	Net international migration by sex, age, and over time
Parameters	
$\emptyset_s \quad s = \{f,m\}$	Probability of sex at birth
$\alpha_{A^*,t}$ $A^* = \{15,16,.....49\} \in (f,A)$	Age-specific fertility rate for women of reproductive age of 15 to 49 years
$\delta_{s,A,d,t}$	Sex, age, and disease specific death rates over time
$\gamma_{s,A,t}$	Sex and age specific net international migration rate
Forcing functions: $I_{s,A,t}$ (default or status quo value = 1) $I^{\delta}_{s,A,t}$ $I^{\alpha}_{s,A,t}$ $I^{\gamma}_{s,A,t}$	Scale-up (-down) functions (over time) corresponding to trend, targets, and/or implementation sequences: ▪ Death rates scale up/down over time ▪ Fertility rates scale up/down over time ▪ Net international migration rate scale up/down over time
Equations	
$P_{s,A+1,t+1} = P_{s,A,t} - D_{s,A,t} + NM_{s,A,t}$	Population Dynamics
$B_{s,t} = P_{s,A=0,t} = \emptyset_s B_{A=0,t}$	Births during year
$B_t = \sum_{f,A^*=15}^{49} B_{A^*,t}$ $B_{A^*,t} = \alpha_{A^*,t} P_{f,A^*}$	Births by age of mother
$D_{s,A,d,t} = \delta_{s,A,d,t} P_{s,A,t}$	Mortality by sex, age, causes of death, and over time

Table 2: Number of deaths and deaths averted from 4 major NCDs

	Deaths and deaths averted in 2025			Deaths and deaths averted in 2030			Cumulative number of deaths and deaths averted: 2015 - 2030		
	Male	**Female**	**Total**	**Male**	**Female**	**Total**	**Male**	**Female**	**Total**
Cardiovascular Diseases									
Number of Deaths									
Status quo	201855	197674	399529	233286	221785	455071	2941995	2848791	5790786
Trend	190594	190362	380956	216656	209789	426445	2811221	2762955	5574176
NCD target	177561	174676	352237	187428	174515	361943	2660692	2583760	5244452
Deaths averted in NCD target scenario									
Compared to status quo	24294	22998	47292	45858	47270	93128	281303	265031	546334
Compared to trend	13033	15686	28719	29228	35274	64502	150529	179195	329724
Respiratory Diseases									
Number of Deaths									
Status quo	72281	55699	127980	83263	62269	145532	1052912	803010	1855922
Trend	64573	52509	117082	70714	56638	127351	961455	764835	1726290
NCD target	62996	48960	111955	68035	49067	117103	945033	724943	1669976
Deaths averted in NCD target scenario									
Compared to status quo	9286	6740	16025	15228	13202	28430	107880	78067	185946
Compared to trend	1577	3549	5127	2678	7570	10249	16422	39892	56314
Diabetes									
Number of Deaths									
Status quo	17105	26292	43396	19589	28871	48461	249695	379623	629318
Trend	16722	27028	43750	19305	30613	49918	245802	389348	635149
NCD target	15284	23723	39006	16057	22855	38911	229151	350952	580103
Deaths averted in NCD target scenario									
Compared to status quo	1821	2569	4390	3532	6017	9549	20544	28671	49215
Compared to trend	1438	3306	4744	3248	7759	11007	16651	38396	55046
Neoplasm									
Number of Deaths									
Status quo	80397	68028	148424	92362	79226	171588	1176825	988663	2165488
Trend	80244	69179	149424	93368	81731	175100	1177349	1003368	2180717
NCD target	71520	60299	131819	73283	60650	133933	1075527	898854	1974381
Deaths averted in NCD target scenario									
Compared to status quo	8876	7729	16605	19079	18576	37655	101298	89809	191107
Compared to trend	8724	8881	17605	20086	21081	41167	101822	104514	206336

Note: Calculations derived from the model.

Table 3: **Life expectancy, Infant mortality rate, Under-five mortality, Probability of dying age 0-70**

	2015	2020	2025	2030	2015	2020	2025	2030
	Male				Female			
Life expectancy at birth								
Status quo	71.10	71.10	71.10	71.10	73.68	73.68	73.68	73.68
Trend	71.10	71.84	72.55	73.23	73.68	74.20	74.68	75.11
NCD target	71.10	71.84	73.07	74.40	73.68	74.19	75.43	76.76
Life expectancy at age 30								
Status quo	43.79	43.79	43.79	43.79	46.36	46.36	46.36	46.36
Trend	43.79	44.31	44.80	45.27	46.36	46.63	46.86	47.04
NCD target	43.79	44.31	45.34	46.45	46.36	46.62	47.62	48.71
Life expectancy at age 65								
Status quo	14.56	14.56	14.56	14.56	15.87	15.87	15.87	15.87
Trend	14.56	14.86	15.16	15.45	15.87	16.01	16.13	16.23
NCD target	14.56	14.86	15.53	16.28	15.87	16.01	16.69	17.47
Infant mortality rate								
Status quo	31.24	31.24	31.24	31.24	27.79	27.79	27.79	27.79
Trend	31.24	27.93	24.69	21.54	27.79	24.83	21.96	19.16
NCD target	31.24	27.93	24.62	21.38	27.79	24.83	21.89	19.01
Under-five mortality rate								
Status quo	38.16	38.16	38.16	38.16	34.54	34.54	34.54	34.54
Trend	38.16	34.10	30.14	26.28	34.54	30.86	27.28	23.80
NCD target	38.16	34.10	30.05	26.09	34.54	30.86	27.19	23.61
Probability of dying age 0-70								
Status quo	459.28	459.28	459.28	459.28	361.27	361.27	361.27	361.27
Trend	459.28	433.02	409.00	387.22	361.27	345.59	331.69	319.58
NCD target	459.28	432.96	389.76	347.54	361.27	346.17	311.19	276.63
Probability of dying age 15-70								
Status quo	415.72	415.72	415.72	415.72	320.83	320.83	320.83	320.83
Trend	415.72	393.92	374.25	356.72	320.83	309.38	299.61	291.53
NCD target	415.72	393.86	355.14	317.33	320.83	309.96	279.24	248.85

Note: Calculations derived from the model.

Figure 1: Overview of the cohort-component population model: stock, flows, and simulation options*

Note: *The model is developed using the Vensim DSS (version 8) simulation platform. **dr**: death rate. **cmpn**: communicable, maternal, perinatal and nutritional conditions; **cvd**: Cardiovascular diseases; **rsp**: Respiratory diseases; **dbt**: Diabetes mellitus; **npl**: neoplasms; **oth**: Other NCDs and Injuries.

Figure 2: Population outlook for Bangladesh: 2015 – 2030 (M: Million)
Note: Calculations derived from the model.

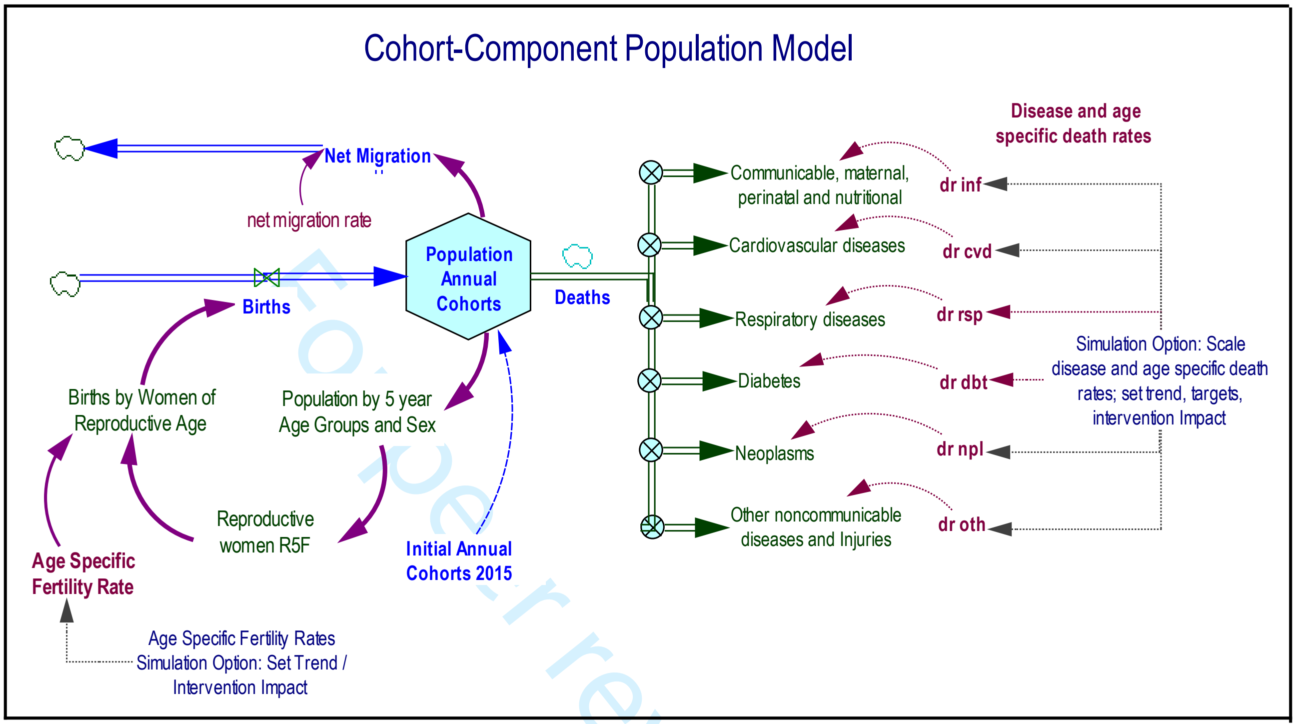
Figure 3: Projected Population age structure in Bangladesh: 2015 and 2030
Note: Calculations derived from the model.

Figure 4: Child, old-age, and total dependency ratios
Note: Calculations derived from the model.

Figure 5: Number of women in reproductive age (15 – 49 years)
Note: Calculations derived from the model.

Figure 6: Mortality by diseases
Note: Calculations derived from the model.

Figure 1: Overview of the cohort-component population model: stock, flows, and simulation options*



Note: *The model is developed using the Vensim DSS (version 8) simulation platform. **dr**: death rate. **cmpn**: communicable, maternal, perinatal and nutritional conditions; **cvd**: Cardiovascular diseases; **rsp**: Respiratory diseases; **dbt**: Diabetes mellitus; **npl**: neoplasms; **oth**: Other NCDs and Injuries.

Figure 2: Population outlook for Bangladesh: 2015 – 2030 (M: Million)

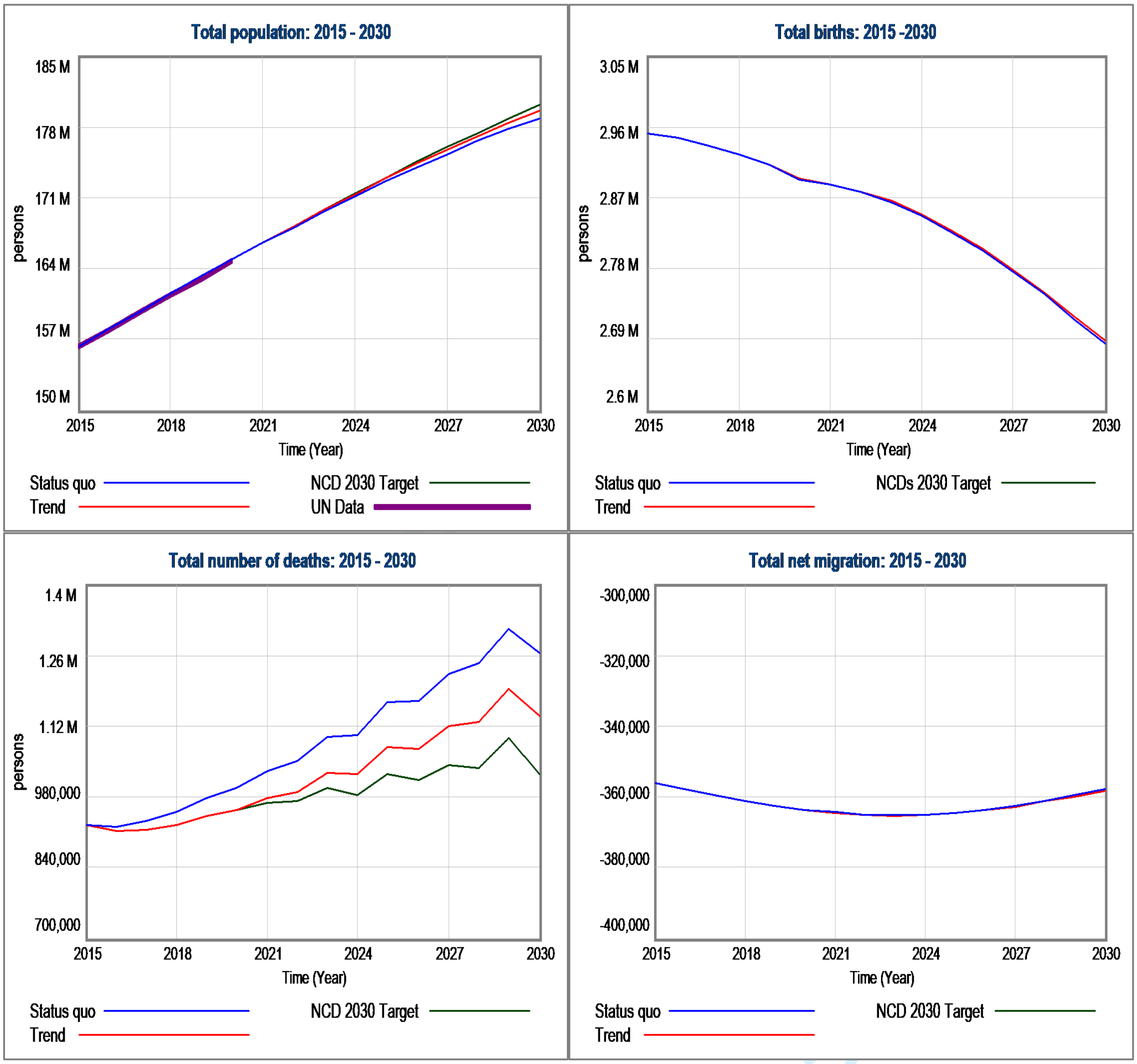
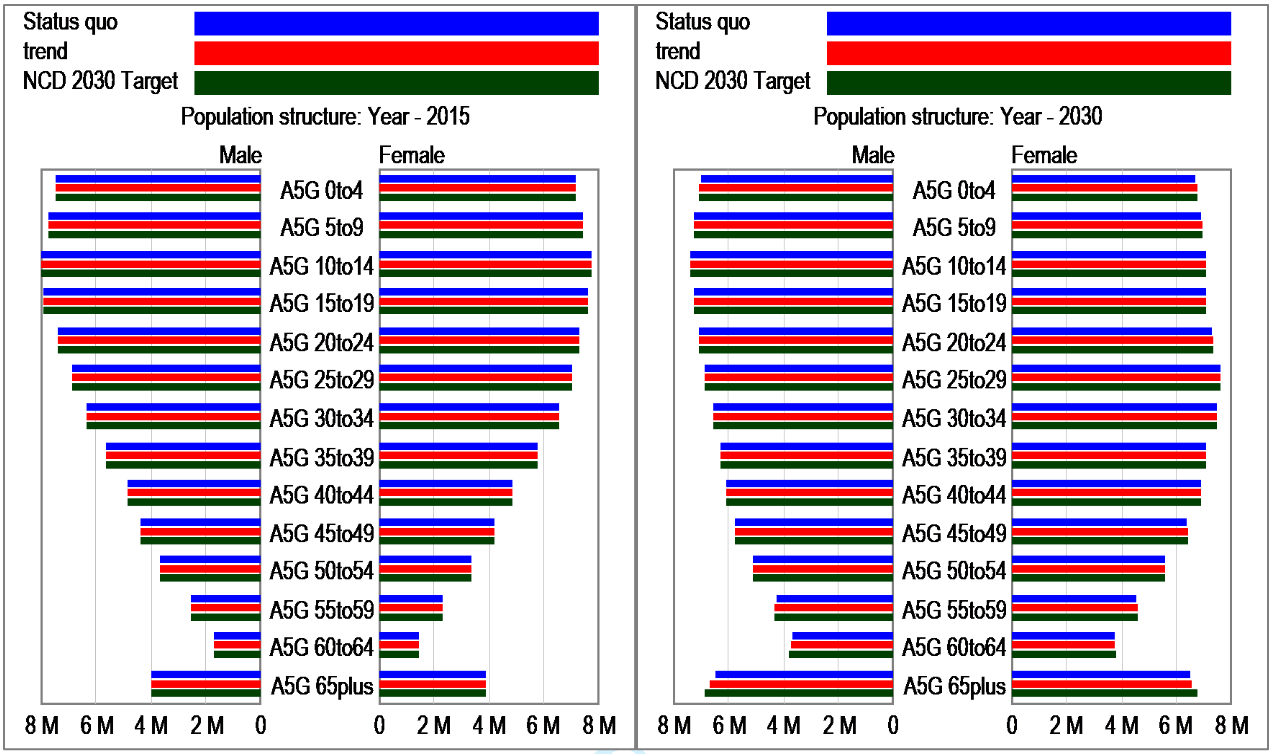
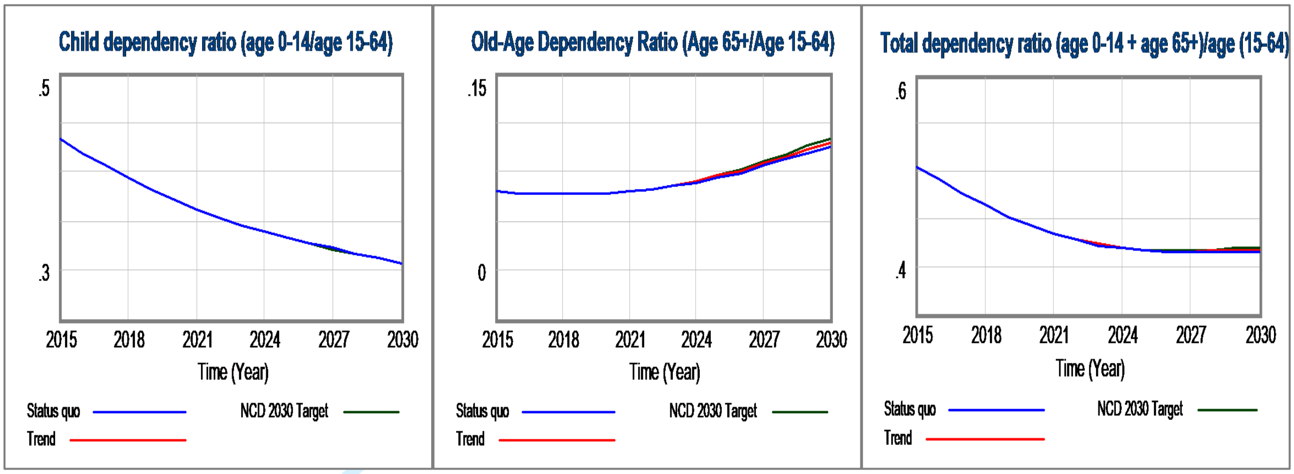


Figure 3: **Projected Population age structure in Bangladesh: 2015 and 2030**



Note: Calculations derived from the model.

Figure 4: **Child, old-age, and total dependency ratios**



Note: Calculations derived from the model.

Figure 5: Number of women in reproductive age (15 – 49 years)

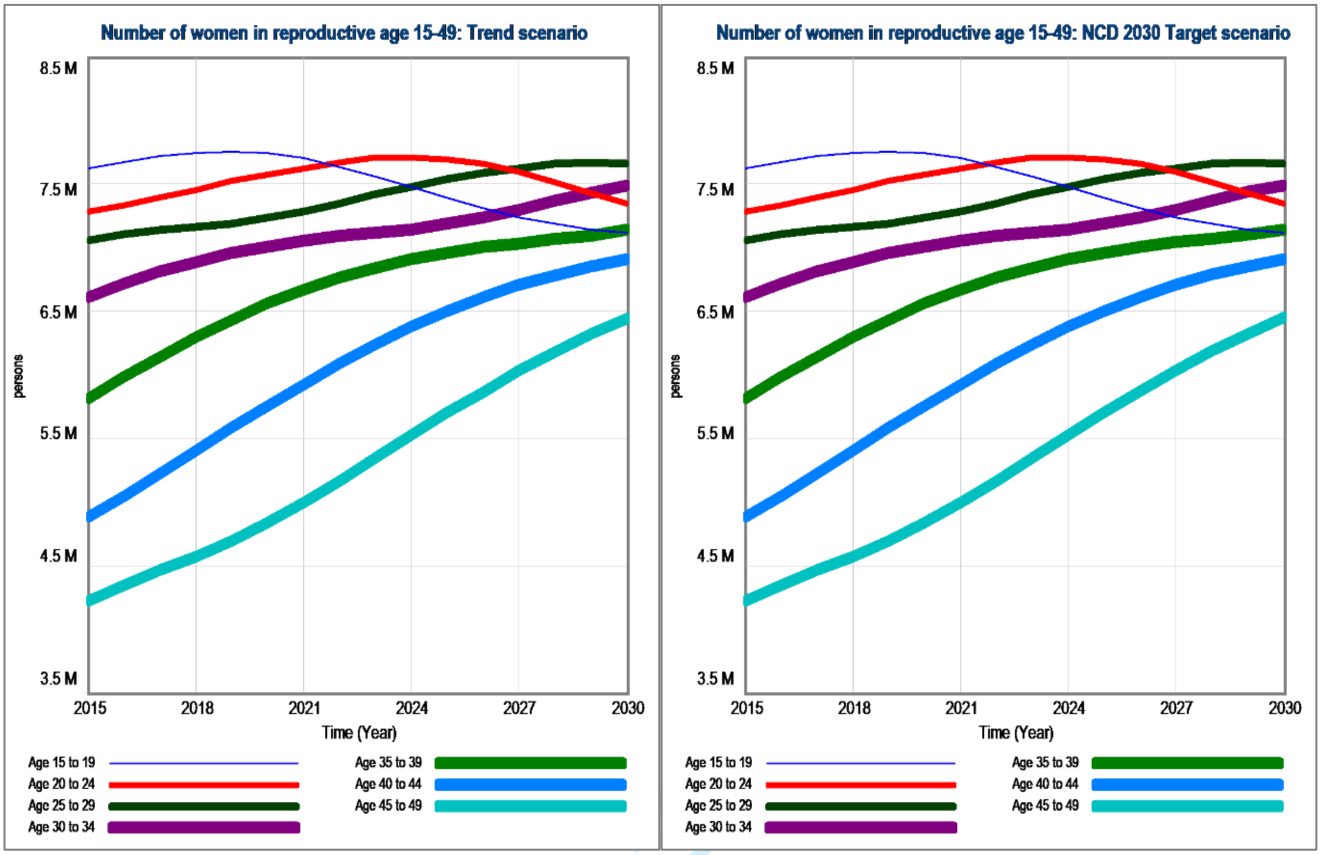
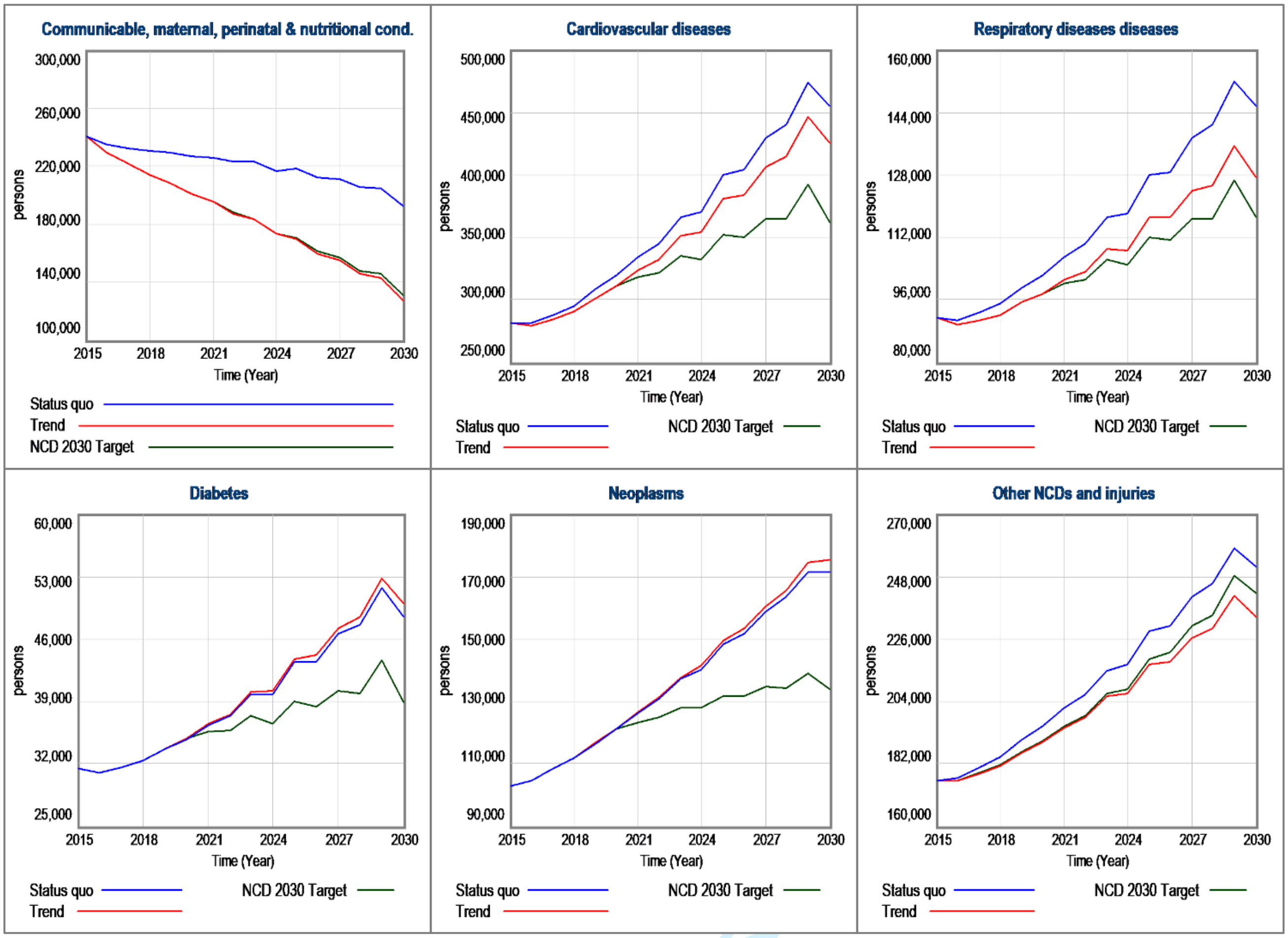


Figure 6: Mortality by diseases



Note: Calculations derived from the model.

Supplementary Table S1: Mapping of disease categories

Broad groups	WHO GHE Code	GHE Cause name*
Communicable, maternal, perinatal and nutritional conditions	I.A. Infectious and parasitic diseases	(1-12): Tuberculosis; STDs excluding HIV; HIV/AIDS; Diarrhoeal diseases; Childhood-cluster diseases; Meningitis; Encephalitis; Hepatitis; Parasitic and vector diseases; Intestinal nematode infections; Leprosy; Other infectious diseases
	I.B. Respiratory Infectious	(1-3): Lower respiratory infections; Upper respiratory infections; Otitis media
	I.C. Maternal conditions	
	I.D. Neonatal conditions	(1-4): Preterm birth complications; Birth asphyxia and birth trauma; Neonatal sepsis and infections; Other neonatal conditions
	I.E. Nutritional deficiencies	(1-5): Protein-energy malnutrition; Iodine deficiency; Vitamin A deficiency; Iron-deficiency anaemia; Other nutritional deficiencies
Neoplasms	II.A. Malignant neoplasms	(1-24): Mouth and oropharynx cancers; Oesophagus cancer; Stomach cancer; Colon and rectum cancers; Liver cancer; Pancreas cancer; Trachea, bronchus, lung cancers; Melanoma and other skin cancers; Breast cancer; Cervix uteri cancer; Corpus uteri; cancer; Ovary cancer; Prostate cancer; Testicular cancer; Kidney cancer; Bladder cancer; Brain and nervous system cancers; Gallbladder and biliary tract cancer; Larynx cancer; Thyroid cancer; Mesothelioma; Lymphomas, multiple myeloma; Leukaemia; Other malignant neoplasms
	II.B. Other neoplasms	
Diabetes	II.C. Diabetes mellitus	
Cardiovascular diseases	II. H. Cardiovascular diseases	(1-6): Rheumatic heart disease; Hypertensive heart disease; Ischaemic heart disease; Stroke; Cardiomyopathy, myocarditis, endocarditis; Other circulatory diseases
Respiratory diseases	II.I. Respiratory diseases	(1-3): Chronic obstructive pulmonary disease; Asthma; Other respiratory diseases
Other NCDs and Injuries	II.D. Endocrine, blood, immune disorders	(1-4): Thalassaemias; Sickle cell disorders and trait; Other haemoglobinopathies and haemolytic anaemias; Other endocrine, blood and immune disorders
	II.E. Mental and substance use disorders	(1-11): Depressive disorders; Bipolar disorder; Schizophrenia; Alcohol use disorders; Drug use disorders; Anxiety disorders; Eating disorders; Autism and Asperger syndrome; Childhood behavioural disorders; Idiopathic intellectual disability; Other mental and behavioural disorders
	II.F. Neurological conditions	(1-7): Alzheimer disease and other dementias; Parkinson disease; Epilepsy; Multiple sclerosis; Migraine; Non-migraine headache; Other neurological conditions
	II. J. Digestive diseases	(1-9): Peptic ulcer disease; Cirrhosis of the liver; Appendicitis; Gastritis and duodenitis; Paralytic ileus and intestinal obstruction; Inflammatory bowel disease; Gallbladder and biliary diseases; Pancreatitis; Other digestive diseases
	II.K. Genitourinary diseases	(1-6): Kidney diseases; Benign prostatic hyperplasia; Urolithiasis; Other urinary diseases; Infertility; Gynecological diseases
	II.L. Skin diseases	
	II.M. Musculoskeletal diseases	(1-5): Rheumatoid arthritis; Osteoarthritis; Gout; Back and neck pain; Other musculoskeletal disorders
	II.N. Congenital anomalies	(1-6): Neural tube defects; Cleft lip and cleft palate; Down syndrome; Congenital heart anomalies; Other chromosomal anomalies; Other congenital anomalies
	II.O: Oral conditions	
	II.P. Sudden infant death syndrome	
	III.A. Unintentional injuries	(1-8): Road injury; Poisonings; Falls; Fire, heat and hot substances; Drowning Exposure to mechanical forces; Natural disasters; Other unintentional injuries
	III.B. Intentional injuries	(1-3): Self-harm; Interpersonal violence; Collective violence and legal intervention

Note: * See Annex Table A in: World Health Organization. (2018). WHO methods and data sources for global burden of disease estimates 2000-2016. *Global Health Estimates Technical Paper WHO/HIS/IER/GHE/2018.4, WHO, Geneva*.

Supplementary Table S2: Demographic Indicators

Indicators	Description
Annual population	Annual population by sex and annual cohorts (age 0 – 100+), by age-groups
Annual population age structure	Population and share of total population by five-year age groups – by sex; Five-year age-groups: age 0 – 4, age 5 – 9, age 10 – 14, age 15 – 19, age 20 – 24, age 25 – 29, age 30 – 34, age 35 – 39, age 40 – 44, age 45 – 49, age 50 – 54, age 55 – 59, age 60 – 64, age 65 and above.
Total, child, and old-age dependency ratios	(i) Total Dependency Ratio ((Age 0-14 + Age 65+) / Age 15-64); (ii) Total Dependency Ratio ((Age 0-19 + Age 65+) / Age 20-64); (iii) Child Dependency Ratio (Age 0-14 / Age 15-64); (iv) Child Dependency Ratio (Age 0-19 / Age 20-64); (v) Old-Age Dependency Ratio (Age 65+ / Age 15-64); (vi) Old-Age Dependency Ratio (Age 65+ / Age 20-64)
Number of births	Annual number of births by sex
Crude birth rate	Average annual number of births per 1,000 population.
Age-specific fertility rate	Number of births to women in a particular age group, divided by the number of women in that age group. The age groups used are: 15-19, 20-24, ..., 45-49.
Total fertility	The average number of live births a cohort of women would have at the end of their reproductive period if they were subject during their whole lives to the fertility rates of a given period and if they were not subject to mortality. It is expressed as live births per woman.
Net reproduction rate	The average number of daughters a cohort of women would have at the end of their reproductive period if they were subject during their whole lives to the fertility rates and the mortality rates of a given period. It is expressed as number of daughters per woman.
Rate of natural population increase	The difference between the number of live births and the number of deaths occurring in a year, divided by the population of that year, multiplied by a factor (usually 1,000). It is equal to the difference between the crude birth rate and the crude death rate.
Crude death rate	Average annual number of deaths per 1,000 population.
Number of deaths	Total annual number of deaths, by sex and annual cohorts.
Death rate or mortality rate	A measure of the number of deaths (in general, or due to a specific cause) in a population, scaled to the size of that population, per unit of time (e.g. the number of deaths per one thousand people per year).
Deaths by diseases	Total annual number of deaths; by sex and annual cohorts; by six broad disease categories: communicable, maternal, perinatal and nutritional conditions; neoplasms; diabetes; cardiovascular diseases; respiratory diseases; other noncommunicable diseases and Injuries.
Infant mortality rate	Probability of dying between birth and exact age 1; expressed as average annual deaths per 1,000 births.
Under-five mortality rate	Probability of dying between birth and age 5; expressed as average annual deaths per 1,000 births.
Probabilities of dying between age 0 to 70	Probability of Dying between Age 0 and Age 70 – by male and female; expressed as deaths under age 70 per 1,000 live births.
Probabilities of dying between 15 and 70	Adult Mortality: Probability of Dying between Age 15 and Age 70 – by male and female. It is expressed deaths under age 70 per 1,000 alive at age 15.
Life expectancy at birth	The average number of years that a newborn could expect to live if he or she were to pass through life exposed to the sex- and age-specific death rates prevailing at the time of his or her birth, for a specific year, in a given country.
Life expectancy at age *'x'* years	The average number of years that a person of *'x'* years of age could expect to live if exposed to the sex- and age-specific death rates prevailing at the time of his/her X_{th} birthday
Crude net migration rate:	The ratio of net migration during the year to the average population in that year. The value is expressed per 1 000 inhabitants.
Total net migration	Number of migrants, that is, the number of immigrants minus the number of emigrants.
Years of lives lost	The years of potential life lost due to premature deaths calculated by summing up number of deaths at each age multiplied by life expectancy at the age at which death occurs

Source: United Nations, Department of Economic and Social Affairs, Population Division (2013). World Population Prospects: The 2012 Revision.

Supplementary Table S3: Baseline data for 2015

Age	Fertility rate		Death rate: Total		Death rate: INF		Death rate: CVD		Death rate: DBT		Death rate: RSP		Death rate: NPL		Death rate: OTH		Net migration rate	
	Per 1000 women		Per 1000 people															
	Data	Calib.*	M**	F**	M	F	M	F	M	F	M	F	M	F	M	F	M	F
< 1 years			31.74	28.18	24.92	22.13	0.12	0.11	0.01	0.01	0.06	0.10	0.31	0.33	6.34	5.50	0.00	0.00
1 – 4 years			1.73	1.69	1.36	1.33	0.01	0.01	0.00	0.00	0.00	0.01	0.02	0.02	0.35	0.33	0.00	0.00
5 - 9 years			0.55	0.66	0.20	0.35	0.01	0.02	0.00	0.00	0.00	0.01	0.03	0.03	0.30	0.25	0.29	0.16
10 – 14 years			0.53	0.52	0.20	0.27	0.01	0.01	0.00	0.00	0.00	0.01	0.03	0.02	0.29	0.20	0.83	0.20
15 - 19 years	75	77	0.83	0.86	0.16	0.30	0.07	0.08	0.00	0.01	0.01	0.03	0.05	0.06	0.53	0.38	-6.17	-0.24
20 – 24 years	137	140	0.94	0.88	0.18	0.31	0.08	0.08	0.00	0.01	0.02	0.03	0.06	0.06	0.61	0.39	-16.49	-0.54
25 – 29 years	105	105	1.06	1.06	0.20	0.37	0.09	0.10	0.00	0.01	0.02	0.04	0.07	0.08	0.68	0.47	-11.70	-0.19
30 - 34 years	56	56	1.33	1.30	0.31	0.25	0.34	0.28	0.02	0.03	0.05	0.06	0.21	0.41	0.41	0.26	-7.46	-0.19
35 - 39 years	25	25	1.79	1.65	0.41	0.32	0.45	0.36	0.02	0.04	0.06	0.08	0.28	0.52	0.56	0.33	-6.12	0.01
40 - 44 years	9	9	2.81	2.09	0.65	0.41	0.71	0.45	0.03	0.05	0.10	0.10	0.44	0.66	0.88	0.41	-3.63	0.16
45 - 49 years	3	3	4.53	2.76	1.04	0.54	1.15	0.60	0.05	0.07	0.16	0.13	0.72	0.88	1.41	0.54	-1.74	0.16
50 – 54 years			8.33	5.01	1.58	0.51	2.84	1.55	0.12	0.16	0.56	0.37	1.61	1.71	1.60	0.72	-0.34	0.14
55 – 59 years			11.39	8.29	2.17	0.84	3.89	2.56	0.17	0.26	0.77	0.62	2.21	2.83	2.19	1.19	-0.13	0.12
60 – 64 years			22.99	16.37	4.13	1.54	8.92	7.55	0.55	0.77	2.79	2.12	3.28	2.26	3.32	2.13	-0.04	0.07
65 – 69 years			27.91	24.38	5.01	2.30	10.83	11.25	0.67	1.14	3.38	3.15	3.98	3.37	4.03	3.17	0.21	0.06
70 – 74 years			56.59	45.38	12.57	7.03	18.84	20.16	2.22	3.09	8.94	5.87	5.80	2.27	8.22	6.96	0.21	0.06
75 – 79 years			60.00	46.35	13.33	7.18	19.97	20.59	2.36	3.16	9.48	6.00	6.14	2.31	8.72	7.11	0.21	0.06
80 – 84 years			90.37	71.99	20.07	11.16	30.08	31.98	3.55	4.90	14.28	9.32	9.25	3.59	13.13	11.04	0.21	0.06
85 year			151.53	125.05	33.66	19.38	50.44	55.55	5.95	8.52	23.94	16.18	15.52	6.24	22.02	19.17	0.21	0.06
90 year			434.35	416.70	96.49	64.59	144.59	185.11	17.05	28.38	68.63	53.92	44.48	20.81	63.12	63.89	0.21	0.06
95 year			717.18	708.35	159.31	109.79	238.73	314.67	28.16	48.25	113.32	91.67	73.45	35.37	104.22	108.60	0.21	0.06
100 and above			1000	1000	222.1	155.00	332.88	444.24	39.26	68.12	158.00	129.41	102.41	49.93	145.31	153.32	0.21	0.06

Note: * 2015 age-group specific fertility data obtained from the Bangladesh Burau of Statistics produced total fertility rate of 2.05; the data has been calibrated up to produce a total fertility rate of 2.10 for 2015. ** **M:** Male; **F:** Female

Supplementary Table S4: The scale factors ($I^{\delta}_{s,A,t}$) for the 'trend' and 'NCD target' mortality rate trajectories

Age	Scenario	Male			Female			Male			Female		
		2015	2020	2030	2015	2020	2030	2015	2020	2030	2015	2020	2030
		Infectious, Maternal, Perinatal, Nutritional						Cardiovascular Disease					
Age 0-4	*Trend*	1.000	0.869	0.608	1.000	0.867	0.602	1.000	0.955	0.866	1.000	0.931	0.794
	Target	1.000	0.869	0.608	1.000	0.867	0.602	1.000	0.955	0.750	1.000	0.931	0.750
Age 5-14	*Trend*	1.000	0.849	0.547	1.000	0.848	0.544	1.000	0.972	0.915	1.000	0.961	0.882
	Target	1.000	0.849	0.547	1.000	0.848	0.544	1.000	0.972	0.750	1.000	0.961	0.750
Age 15-29	*Trend*	1.000	0.842	0.526	1.000	0.850	0.549	1.000	0.924	0.771	1.000	0.929	0.788
	Target	1.000	0.842	0.526	1.000	0.850	0.549	1.000	0.924	0.750	1.000	0.929	0.750
Age 30-49	*Trend*	1.000	0.842	0.525	1.000	0.848	0.544	1.000	0.948	0.845	1.000	0.940	0.821
	Target	1.000	0.842	0.525	1.000	0.848	0.544	1.000	0.948	0.750	1.000	0.940	0.750
Age 50-69	*Trend*	1.000	0.871	0.612	1.000	0.889	0.666	1.000	0.965	0.895	1.000	0.963	0.889
	Target	1.000	0.871	0.612	1.000	0.889	0.666	1.000	0.965	0.750	1.000	0.963	0.750
Age 70+	*Trend*	1.000	0.923	0.769	1.000	0.931	0.792	1.000	0.963	0.888	1.000	0.989	0.966
	Target	1.000	0.923	0.769	1.000	0.931	0.792	1.000	0.963	0.750	1.000	0.989	0.750
		Respiratory Disease						Neoplasm					
Age 0-4	*Trend*	1.000	0.947	0.842	1.000	0.915	0.746	1.000	1.040	1.119	1.000	1.036	1.107
	Target	1.000	0.947	0.750	1.000	0.915	0.750	1.000	1.040	0.750	1.000	1.036	0.750
Age 5-14	*Trend*	1.000	0.954	0.863	1.000	0.932	0.797	1.000	0.987	0.960	1.000	0.992	0.975
	Target	1.000	0.954	0.750	1.000	0.932	0.750	1.000	0.987	0.750	1.000	0.992	0.750
Age 15-29	*Trend*	1.000	0.912	0.737	1.000	0.918	0.755	1.000	0.989	0.967	1.000	0.987	0.960
	Target	1.000	0.912	0.750	1.000	0.918	0.750	1.000	0.989	0.750	1.000	0.987	0.750
Age 30-49	*Trend*	1.000	0.910	0.731	1.000	0.945	0.836	1.000	0.983	0.950	1.000	1.005	1.014
	Target	1.000	0.910	0.750	1.000	0.945	0.750	1.000	0.983	0.750	1.000	1.005	0.750
Age 50-69	*Trend*	1.000	0.929	0.788	1.000	0.966	0.897	1.000	0.984	0.953	1.000	0.999	0.998
	Target	1.000	0.929	0.750	1.000	0.966	0.750	1.000	0.984	0.750	1.000	0.999	0.750
Age 70+	*Trend*	1.000	0.940	0.820	1.000	0.969	0.907	1.000	1.004	1.012	1.000	1.029	1.086
	Target	1.000	0.940	0.750	1.000	0.969	0.750	1.000	1.004	0.750	1.000	1.029	0.750
		Diabetes						Other NCDs and Injuries					
Age 0-4	*Trend*	1.000	0.981	0.942	1.000	0.988	0.964	1.000	0.967	0.902	1.000	0.975	0.925
	Target	1.000	0.981	0.750	1.000	0.988	0.750	1.000	0.967	0.902	1.000	0.975	0.925
Age 5-14	*Trend*	1.000	0.982	0.947	1.000	0.966	0.898	1.000	0.971	0.914	1.000	0.974	0.923
	Target	1.000	0.982	0.750	1.000	0.966	0.750	1.000	0.971	0.914	1.000	0.974	0.923
Age 15-29	*Trend*	1.000	0.931	0.793	1.000	0.953	0.860	1.000	0.963	0.888	1.000	0.942	0.827
	Target	1.000	0.931	0.750	1.000	0.953	0.750	1.000	0.963	0.888	1.000	0.942	0.827
Age 30-49	*Trend*	1.000	0.961	0.883	1.000	1.010	1.030	1.000	0.953	0.859	1.000	0.953	0.859
	Target	1.000	0.961	0.750	1.000	1.010	0.750	1.000	0.953	0.859	1.000	0.953	0.859
Age 50-69	*Trend*	1.000	0.975	0.925	1.000	1.011	1.034	1.000	0.963	0.890	1.000	0.970	0.911
	Target	1.000	0.975	0.750	1.000	1.011	0.750	1.000	0.963	0.890	1.000	0.970	0.911
Age 70+	*Trend*	1.000	0.979	0.936	1.000	1.010	1.031	1.000	0.975	0.926	1.000	0.987	0.961
	Target	1.000	0.979	0.750	1.000	1.010	0.750	1.000	0.975	0.926	1.000	0.987	0.961

Note: The 'trend' scenario adopts sex, age-group and disease-specific mortality rate trajectories based on the latest WHO GHE regional mortality projections 2016-2030 for 'Southern Asia' consisting of Afghanistan, Bangladesh, Bhutan, India, Iran, Maldives, Nepal, Pakistan, and Sri Lanka. (WHO 2020, Mathers 2006)22,23 The scale factors in both the trend and the NCD target scenarios are same until 2020.

Supplementary Table S5: Years of lives lost (YLL) and YLL averted

	YLL and YLL averted in 2025			YLL and YLL averted in 2030			Cumulative number of YLL and YLL averted: 2015 - 2030		
	Male	**Female**	**Total**	**Male**	**Female**	**Total**	**Male**	**Female**	**Total**
Cardiovascular Diseases									
Years of lives lost (YLL)									
Status quo	2803780	2555540	5359320	3296620	3138670	6435290	41559630	37650010	79209640
Trend	2702700	2425290	5127990	3133850	2904330	6038180	40340000	36062190	76402190
NCD target	2571870	2318060	4889930	2823830	2642440	5466270	38793880	34784950	73578830
YLL averted in NCD target scenario									
Compared to status quo	231910	237480	469390	472790	496230	969020	2765750	2865060	5630810
Compared to trend	130830	107230	238060	310020	261890	571910	1546120	1277240	2823360
Respiratory Diseases									
Years of lives lost (YLL)									
Status quo	799237	709026	1508263	961304	868787	1830091	11865109	10476692	22341801
Trend	726429	665852	1392281	832200	790956	1623156	10973367	9947147	20920514
NCD target	727049	641380	1368429	838620	732037	1570657	10991537	9657422	20648959
YLL averted in NCD target scenario									
Compared to status quo	72188	67646	139834	122684	136750	259434	873572	819270	1692842
Compared to trend	-620	24472	23852	-6420	58919	52499	-18170	289725	271555
Diabetes									
Years of lives lost (YLL)									
Status quo	186760	305995	492755	223575	375357	598932	2784911	4537873	7322784
Trend	186088	316486	502574	224059	395749	619808	2778522	4668447	7446969
NCD target	174079	284944	459023	195118	317891	513009	2635534	4290234	6925768
YLL averted in NCD target scenario									
Compared to status quo	12681	21051	33732	28457	57466	85923	149377	247639	397016
Compared to trend	12009	31542	43551	28941	77858	106799	142988	378213	521201
Neoplasm									
Years of lives lost (YLL)									
Status quo	1366430	1592810	2959240	1565490	1852850	3418340	20385990	23528850	43914840
Trend	1390400	1627500	3017900	1613330	1913180	3526510	20685340	23950710	44636050
NCD target	1264270	1455890	2720160	1320630	1510980	2831610	19208460	21933760	41142220
YLL averted in NCD target scenario									
Compared to status quo	102160	136920	239080	244860	341870	586730	1177530	1595090	2772620
Compared to trend	126130	171610	297740	292700	402200	694900	1476880	2016950	3493830

Note: Calculations derived from the model.

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Disease and demography: A Systems-dynamic cohort-component population model to assess the implications of disease-specific mortality targets

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Abstract

Introduction: The 2015 Sustainable Development Goals include the objective of reducing premature mortality from major noncommunicable diseases by one-third by 2030. Accomplishing this objective has demographic implications with relevance for countries' health systems and costs. However, evidence on the system-wide implications of NCD targets is limited.

Methods: We developed a cohort-component model to estimate demographic change based on user-defined disease-specific mortality trajectories. The model accounts for aging over 101 annual age cohorts, disaggregated by sex, and projects changes in the size and structure of the population. We simulated demographic outlooks for Bangladesh for 2015-2030 using three mortality scenarios. The 'status quo' scenario entails that the disease-specific mortality rate profile observed in 2015 applies throughout 2015-2030. The 'trend' scenario adopts age-, sex- and disease-specific mortality rate trajectories projected by WHO for the region. The 'target' scenario entails a one-third reduction in the mortality rates of cardiovascular disease, cancer, diabetes, and chronic respiratory diseases between age 30 and 70 by 2030.

Results: The status quo, trend, and target scenarios project 178.9, 179.7, and 180.2 million population in 2030, respectively. The cumulative number of deaths during 2015–2030 is 17.4, 16.2, and 15.6 million for each scenario, respectively. During 2015 - 2030, the target scenario would avert a cumulative 1.73 million and 584 thousand all-cause deaths compared to the status quo and trend scenarios, respectively. Male life expectancy is estimated to increase from 71.10 to 73.47 years in the trend scenario and 74.38 years in the target scenario; female life expectancy increases from 73.68 to 75.34 years and 76.39 years in the trend and target scenarios, respectively.

Conclusion: The model describes the demographic implications of NCD prevention and control targets. The results can be used to inform future health system needs and support planning for increased healthcare coverage in countries.

Key Words: cohort component model; system dynamics; population projection; Bangladesh; noncommunicable diseases (NCDs); Sustainable Development Goals targets; demography; mortality, fertility, net migration.

Strengths and Limitations of the Study

- The model provides an understanding of how changes in disease-specific mortality may contribute to the demographic outlook of countries by simulating demographic evolution paths corresponding to pre-specified mortality rate outlooks.
- The model tracks population outcomes at a highly disaggregated level and can produce consistent and comparable cross-country estimates for a set of demographic indicators.
- The model uses established principles about the dynamics of the population process and can be flexibly adapted to the intended disaggregation schemes of population cohorts and disease categories.
- The cohort component method does not explicitly incorporate socio-economic determinants of population change.
- The model outcomes are based on conditional calculations producing outlooks for a set of demographic indicators under a particular set of reasonable assumptions.

Introduction

Changes in population size and demographic composition have broad economic and social implications. Informed decisions regarding population-level policies and interventions hinge on robust population projections that delineate the dynamic interplay of demographic processes such as fertility, mortality, and migration. Generating counts for population cohorts of interest determines investment in sectors like health, education, infrastructure, and others.[1, 2]

We present a cohort-component population projection model to assess demographic changes associated with changes in the distribution of causes of death. Current population projections reflect a variety of assumptions about fertility, mortality, and migration.[3-6] For instance, the UN produces eight variants of population projections, five of which are based on different trajectories of fertility, while mortality assumptions are determined by probabilistic trends of life expectancy at birth, and international migration is assumed either constant or zero.[3] The existing population projection models typically emphasize the role of fertility but do not provide an understanding of how changes in disease-specific mortality rates may contribute to the demographic outlook of countries.

Preventable deaths and disability caused by communicable diseases, maternal, perinatal and nutritional conditions (CMPN), noncommunicable diseases (NCDs), and injuries constitute core concerns across nations. Among these, cardiovascular diseases (CVDs) are in the lead, accounting for 15.2 million deaths of all 56.9 million deaths worldwide in 2016.[7] Given the rising significance of NCDs in global health, the 2030 Sustainable Development Goals (SDGs) aim to reduce premature mortality from the four major NCDs (CVDs, diabetes, cancer, and respiratory diseases) by one-third by 2030, relative to 2015 level.[8] With the adoption of the WHO Global NCD Action Plan by the World Health Assembly in 2013, the WHO Member States agreed on a time-bound voluntary target of attaining a 25% relative reduction in overall mortality from the four leading NCDs by 2025.[9] In a similar vein, the WHO 2013 Global Program of Work (GPW 2013) set the target of 20% relative reduction in the premature mortality (age 30-70 years) from these NCDs between 2019-2023.[10] These objectives occur in the context of many budgetary and planning constraints that affect low-income and middle-income countries (LMICs). Further, variations in the incidence and prevalence of diseases across sex and age cohorts require policymakers to formulate targeted interventions and policies. Understanding the evolution of different age-cohorts resulting from shifts in disease-specific mortality over time can inform the resource needs for national scale-up of interventions to attain SDG health targets.

The dynamic population projection model in this study simulates a range of demographic evolution paths corresponding to pre-specified disease-specific mortality outlooks. The results provide demographic information needed to plan for services to meet future demands of different segments of the population. Although the model in this study is applied to Bangladesh, it is replicable across different countries and can serve as a tool for planners to simulate user-defined scenarios corresponding to assumed fertility, mortality, and international migration trajectories.

Over the last several decades, Bangladesh has made substantial progress in disease prevention and control of childhood communicable diseases, but NCDs have emerged as the primary cause of death and disability in the country.[11,12] In response, the Government of Bangladesh (GoB) has formulated an NCD action plan to reduce NCDs and associated risk factors through a multisectoral coordinated approach.[13] Bangladesh NCD prevention and control targets are consistent with the 2030 SDGs and with the WHO South-East Asia regional NCD 2025 objectives of reducing by 25% premature mortality from CVDs, diabetes, respiratory diseases, and cancer.[13,14] Attainment of these targets entails population-level prevention and treatment initiatives. A first step in planning for such initiatives is information on the demographic outcomes associated with accomplishing the health objectives of these initiatives.[15] To this end, the present study models the demographic outlook for Bangladesh from 2015 to 2030 under the assumption of attaining the 2030 SDG target of reducing premature mortality (age 30-70 years) from four major NCDs by one-third. More specifically, we produce the demographic outlook for Bangladesh corresponding to a one-third reduction (i.e., ~30%) in the unconditional probability of dying between the exact ages of 30 and 70 years from any of CVDs, cancer, diabetes, or chronic respiratory diseases.

Methods and Data

Patient and Public Involvement

Patients or the public were not involved in the design, or conduct, or reporting, or dissemination plans of this research.

The systems-dynamic cohort-component population model

We develop a cohort-component population projection model that tracks each sex- and age-specific cohort of people throughout its lifetime, subject to assumed age- and sex-specific mortality, fertility, and migration rates.[6,16] The model represents a "systems" structure defined by the stocks and flows and the connections between them.[17-20] In this model, the population in each year is the stock variable, while births, deaths, and international migration represent the flows. The model starts with defining the initial-year population, disaggregated by sex- and age-cohorts, followed by defining the fertility, mortality, and migration attributes of each cohort throughout the projected horizon. In other words, the model in this study resembles an aging chain where, after birth, each birth cohort progresses from childhood (first stock) to old age (last stock) unless the individual dies and leaves the system.

[Figure 1 here]

Figure 1 presents an overview of the model structure using a stock-and-flow diagram. The population's dynamic path begins with the initial population stock observed in 2015 for Bangladesh, disaggregated by sex and age. In each subsequent year, changes in the annual population stock occur through adding births, subtracting deaths, and through net international migration (emigration minus immigration) as expressed in Equation 1.

Population dynamics: $$P_{s,A+1,t+1} = P_{s,A,t} + B_{s,t} - D_{s,A,t} + NM_{s,A,t} \quad (1)$$

$P_{s,A,t}$ is population by sex ($s = \{f, m\}$), 101 annual age cohorts ($A = \{0,1,2,.....100\}$) at year $t = \{0,1,2,...T\}$ (i.e., over 2015 – 2030). $B_{s,t}$ is the number of annual births, determined by applying exogenously set age-specific fertility rates to the cohorts of reproductive-age women (age 15-49).

Births during year: $$B_{s,t} = P_{s,A=0,t} = \emptyset_s B_{A=0,t} \quad (2)$$

Total births: $$B_t = \sum_{f,A^*=15}^{49} B_{A^*,t} \quad (3)$$

Births by age of mother: $$B_{A^*,t} = \alpha_{A^*,t} P_{f,A^*,t} \quad (4)$$

Where $\emptyset_s$ is the probability of sex ($s = \{f, m\}$) at birth; $\alpha_{A^*,t}$ represents age-specific fertility rate for women of reproductive age of 15 to 49 years (i.e., $A^* = \{15,16,.....49\} \in (f, A)$).

In each year, people in each age cohort leave the system due to deaths ($D_{s,A,t}$) and net international migration ($NM_{s,A,t}$). The causes of deaths are aggregated into six major types of disease categories: communicable, maternal, perinatal and nutritional conditions (CMPN); neoplasms; diabetes; cardiovascular diseases; respiratory diseases; other NCDs and injuries.

Mortality by sex, age, causes of death: $$D_{s,A,d,t} = \delta_{s,A,d,t} P_{s,A,t} \quad (5)$$

Where, $\delta_{s,A,d,t}$ represents sex-, age-, and disease-specific death rates over time; *d* represents the number of deaths from six types of diseases; $d = \{cmpn, npl, dbt, cvd, rsp, othNCDs\}$, *cmpn:* communicable, maternal, perinatal, nutritional (WHO GHE codes I.A., I.B., I.C., I.D., I.E.); *npl*: neoplasms (II.A., II.B.); *dbt:* diabetes (II.C.); *cvd:* cardiovascular diseases (II.H.); *rsp:* respiratory diseases (code II.I.); *othNCDs*: other noncommunicable diseases and injuries (II.D., II.E., II.F., II.J., II.K., II.L., II.M., II.N., II.O., II.P., III.A., II.B.). Sex, age-group, and disease-specific deaths rates determine the number of deaths each year. The Supplementary Table S1 maps these broad categories with the disaggregated WHO Global Health Estimates (GHE) causes of death codes.[21]

Net international migration by sex, age, and over time is defined as:

$$NM_{s,A,t} = P_{s,A,t} * \gamma_{s,A,t} \quad (6)$$

where $\gamma_{s,A,t}$ is sex and age-specific net international migration rate over the years. Depending on country contexts, sex and age-specific net migration rates determine the number of people removed from (or added to) the population due to migration to (or from) other countries.

The model allows the option of simulating different scenarios by setting sex- and age-specific fertility rates; sex-, age-, and disease-specific death rates; and net-migration rates, for each year over the analytic time-horizon (2015 – 2030). For instance, scenarios of different mortality trends could reflect status-quo (i.e., constant death rates over time), trajectories based on historical trends, trajectories based on the predicted impact of disease prevention interventions or reductions in risk factor exposures informed by the literature, or user-defined mortality outlooks based on national plans. We introduce a set of forcing functions ($I_{s,A,t}$) with a default or status quo value of 1 but allow scaling-up (-down) functions (over time) corresponding to trend, targets, and/or any other implementation sequences:

Death rates scale up/down over time: $\delta_{s,A,d,t} * I^{\delta}_{s,A,d,t}$ (7)

Fertility rates scale up/down over time: $\alpha_{A^*,t} * I^{\alpha}_{s=f,A^*,t}$ (8)

Net international migration rate scale up/down over time: $\gamma_{s,A,t} * I^{\gamma}_{s,A,t}$ (9)

The model allows user to set scale factors for different years by sex- and age-groups. For instance, while $I^{\delta}_{s,A,d,t} = 1$ for each year during 2015-2030 in the status quo death rate scenario, $I^{\delta}_{s,A,d,t=2015} = 1$ and $I^{\delta}_{s,A,d,t=2030} = 0.67$ entail 33% reduction in the death rates from the 2015 level; scale factors for the interim years (i.e., 2016-2029) may include linear interpolated values, or concave/convex path, or user-defined values corresponding to interim national targets.

The model generates population counts for 202 annual age-sex cohorts consisting of age 0 – 100+ years for male and female, respectively. Data on fertility, mortality, and net-migration rates were only available by age-group and were assigned to corresponding annual cohorts within each age-group. We used two age-groups depending on data availability, separately for male and female: (1) six broad age-groups: age 0–4, age 4–14, age 15–29, age 30–49, Age 50–69, Age 70 and above; (2) five-year age-groups: age 0–4, age 5–9, age 10–14, age 15–19, age 20–24, age 25–29, age 30–34, age 35–39, age 40–44, age 45–49, age 50–54, age 55–59, age 60–64, age 65 and above.

Demographic Indicators

The model produces several key demographic indicators, including population counts and age structure; total, child, and old-age dependency ratios; the number of births; crude birth rate; total fertility; net reproduction rate; the rate of natural population increase; the number of deaths by diseases; infant and child mortality rates; crude death rate; life expectancy at birth and at each age; the probabilities of dying between age 30 and 70; and total years of lives lost by diseases. The Supplementary Table S2 provides brief definitions of the indicators.[22]

Bangladesh case study: demographic implications of SDG NCD mortality targets

Baseline Data

To initiate the population dynamics, we needed base year population, age-specific fertility rates, age-specific death rates, and age-specific net migration rates. We used the 2015 annual cohort (age 0-100) population data from the UN population projection (medium variant); age-specific fertility rates reported by the Bangladesh Bureau of Statistics; age-specific total death rates are obtained from the UN Life tables for Bangladesh for the year 2015, and age-specific net migration rates from Bangladesh Bureau of Statistics.[3,23,24,25] The UN estimate of the ratio of sex at birth for Bangladesh is 1.05 for their entire analytic horizon; we used the same for this model.[25] The UN lifetable for Bangladesh assumes a 100% mortality rate for ages 85 and above.[25,26] Our model assumed that all people in the last age cohort (100+ years) leave the system (i.e. die) with a 100% mortality rate, with interpolated death rates for ages 85 – 99. The total net migration rate reported in the UN population projection is -2.3/1,000 population; our model assumed the same statistic when applying age-specific net migration rates to the baseline (2015) population.[22,25] We used WHO Global Health Estimate (GHE) disease burden (mortality) data by cause, age, and sex[7] to decompose the total death rates by six broad categories of diseases, so that,

$$\delta_{s,A,d,t=2015} = \frac{GHE\ Death_{S,A,d,t=2015}}{\sum_{d=1}^{6} GHE\ Deaths_{S,A,d,t=2015}} \qquad (10)$$

$$d = \{cmpn, npl, dbt, cvd, rsp, othNCDs\}$$

$$\sum_{d=1}^{6} \delta_{s,A,d,t} = \delta_{s,A,t}$$

Where equation 10 is used to decompose the baseline (year=2015) sex- and age-specific death rates into 6 diseases specific rates and $GHE\ Death_{S,A,d,t=2015}$ represent the number of deaths by diseases obtained from WHO GHE mortality data for the year 2015. $\delta_{s,A,t}$ (i.e. sex- and age-specific death rates at year *t*) is the sum of death rates from 6 broad categories of diseases (*d*). The Supplementary Table S3 reports the 2015 baseline data used in the model, including the death rates by six broad disease categories.

Scenarios

We compared three demographic outlooks for Bangladesh: status quo, trend, and target. The three scenarios differ in terms of their assumed mortality trajectories, keeping fertility and net migration trajectories the same across scenarios. The UN population projection uses five fertility variants: low, medium, high, constant-fertility, and instant-replacement-fertility. For instance, for Bangladesh, during 2015-2020 the total fertility rates are assumed to be 2.2, 2.05, and 1.68 for the high, medium, and low variants, respectively. For the 2025-2030 period the total fertility rates are assumed to be 2.26, 1.82, and 1.42 for the high, medium, and low variants, respectively.[3, 23] We use the 2015 age-specific fertility rates reported by the Bangladesh Bureau of Statistics (BBS), setting the total fertility rate at 2.10. Then, using the UN probabilistic projections for age-specific fertility rates for the 2025-2030 period, we scaled down the respective 2015 age-specific fertility rates to arrive at a total fertility rate of 1.82 by 2030. For the interim years, the model uses interpolated linear trends. We used the 2015 sex- and age-specific net migration rates obtained from BBS, which remains constant during the 2015-2030 period.[23,24]

The study uses three variants of mortality trajectories. The ‘status quo’ scenario entails that the 2015 disease-specific mortality rates remain constant for the analysis horizon, so that $I_{s,A,t}^{\delta}$= 1 for the 2015-2030 period. The ‘trend’ scenario adopts sex, age-group and disease-specific mortality rate trajectories based on the latest WHO GHE regional mortality projections for 2016-2030 for Southern Asia, consisting of Bangladesh and other neighboring countries.[27,28] We estimated the death rates by sex, age-groups, and six broad disease categories for 2016 and 2030 from the number of deaths and total population obtained from WHO GHE study; and then produced a matrix of scale factors such that:

$$I_{s,A,d,t\,=\,2030}^{\delta} = \frac{\delta_{S,A,d,t\,=\,2016}^{GHE}}{\delta_{S,A,d,t\,=\,2030}^{GHE}}.$$

Where $I_{s,A,t\,=\,2030}^{\delta}$ are sex-, age-, and disease-specific scale factors for the death rates in 2030 relative to 2015 levels. The interim years use interpolated scale factors and corresponding mortality rate values. For instance, the WHO GHE estimate projects that by 2030, the death rates of infectious, maternal, perinatal, and nutritional conditions would reduce by 21% for females aged 70 and above and 48% for males aged 15-29 years. Accordingly, we set the death rate trajectories for the corresponding cohorts to reflect 21% and 48% reductions in 2030 from 2015, respectively. Similarly, depending on sex and age-groups, the reductions of death rates range from 3.4% to 22.9% for CVDs; 9.3% to 22.9% for respiratory diseases; and 3.9% to 14.1% for other NCDs and injuries. The trend projections for neoplasms ranges from 9.3% to 22.9% increases in the death rates by 2030. The changes in diabetes death rates ranges from a reduction of 20.7% to an increase of 3.4%. The Supplementary Table S4 reports all sex, age-group, and disease-specific scale factors (**$I_{s,A,d,t}^{\delta}$**) for the trend scenario.

The third scenario is the 'target' scenario, which entails relative reductions in the mortality rates that result in approximately one-third reduction (i.e., ~30%) in the unconditional probability of dying between the ages of 30 and 70 years from any one of CVDs, cancer, diabetes, or chronic respiratory diseases between 2015 and 2030. For the other two disease categories (i.e., communicable, maternal, perinatal, nutritional condition; and other noncommunicable diseases and injuries) we use the same mortality rate trajectories as in the 'trend' scenario. The mortality rate trajectory for the four major NCDs follows the trend scenario until 2020 for all age groups, and then declines by 33% during 2015-2030 for ages 30 to 69 to arrive at the probability of premature deaths representing about one-third reduction relative to 2015 level; i.e. $I^{\delta}_{s,A=30to69,d=cvd,rsp,dbt,npl,t=2030}$=0.67 for 2030 and the interim years use interpolated values. The Supplementary Table S4 reports the $I^{\delta}_{s,A,d,t}$ values under the target scenarios; the scale factors for 2020 are same in the trend and target scenarios but set at 0.67 for ages 30 to 69 for 2030 and four NCDs in the target scenario. In achieving the SDG NCD mortality target at the aggregate level, the death rate trajectories can be non-linear and can differ by sex, age, and/or disease categories. While the model allows incorporating variants of implementation paths, for the sake of simplicity, in this study we assumed linear interpolated scale factors for the analytic horizon.

This cohort component systems dynamic population model has been developed using Vensim DSS for Windows Version 8.0.4 (Double Precision x64) (https://vensim.com/vensim-software/).

Results

Population outlooks

The status quo, trend, and target scenarios project 178.9, 179.7, and 180.2 million population in 2030, respectively. Figure 2 shows the projections for total population along with the three main flow variables in the model, i.e., total births, total deaths, and total net international migration. Given that all fertility and migration assumptions are the same across all three scenarios, differences in the projected population numbers between scenarios reflect differences in the death rate trajectories. The assumption of a steady decline in total fertility from 2.10 in 2015 to 1.82 in 2030 leads to a declining trajectory for the annual number of births from 2.95 million in 2015 to around 2.69 million in 2030. The assumed constant age-specific net migration rate kept the total number of people migrating abroad between 356 and 365 thousand each year. However, the annual number of deaths is much higher in the status quo scenario compared to the trend and target scenarios. The model projects 1.26, 1.12, and 1.04 million deaths in 2030 in the status quo, trend, and target scenario, respectively. The cumulative number of deaths during 2015 – 2030 are 17.37, 16.22, and 15.64 million in the status quo, trend and the target scenario, entailing 1.73 million and 584 thousand deaths averted in the target scenario compared to the status quo and trend scenarios, respectively.

[Figure 2 here]

Figure 3 shows the inverted age-sex pyramid illustrating the distribution of various age groups in Bangladesh in 2015 (left panel) and 2030 (right panel). The population is distributed along the horizontal axis, with males shown on the left and females on the right. The male and female populations are broken down into 5-year age groups represented as horizontal bars along the vertical axis, with the youngest age groups (age 0-4) at the top and the oldest at the bottom (age 65 and above). The shape of the population pyramid gradually evolves during 2015–2030 based on fertility, mortality, and international migration trends. The apparent cone-shaped population pyramid in 2015 appears more symmetric in 2030, consistent with population ageing over the analytic horizon.

[Figure 3 here]

The evolving population structure is also reflected in Figure 4. The rapid reductions in infant and child mortality accompanied by decreasing fertility led to a continuous reduction in the child dependency ratio (i.e., ratio of population age 0-14 and age 15-64) (0.45 in 2015 vs. 0.35 in 2030 trend scenario). On the other hand, as the annual cohorts progress through the analytic period, the old-age dependency ratio (i.e., ratio of population age 65 and above and age 15-64), after remaining relatively flat during 2015 – 2020, starts to rise beyond 2020 (0.78 in 2015; 0.77 in 2020; and ~0.10 in 2030 for the three scenarios). The total dependency ratio (i.e., ratio of population age 0-14 and age 65 and above, and age 15-64) registers a relatively quick decline from 0.52 in 2015 to 0.45 in 2025 and remains at 0.45 until 2030.

[Figure 4 here]

The annual number of births is determined by the age-specific fertility rates and the number of women of reproductive age 15–49 years. The trajectory of the number of women in reproductive age is affected by the number of deaths and international migration for the corresponding cohorts. In figure 5, for the trend and target scenarios, it is evident that the number of women aged 15-19 begins to decline after 2021, and the number of women aged 20-24 declines after 2024. The number of women in all other older age groups increases during 2015 – 2030, with older cohorts showing larger growth.

[Figure 5 here]

Figure 6 presents the projected mortality trajectories by disease categories. The number of deaths from all disease categories increases except for the CMPN category in the status quo scenario. In the status quo scenario, population decreases moderately for younger cohorts (i.e., age<25) and increases more for the older cohorts age 25 and above during 2015-2030 period, leading to net increase in the total population. Consequently, the assumed constant death rates for the CMPN in the status quo scenario results in net increase in total deaths from CMPN. On the other hand, the continuous decline in death rates and a near-flat population trend with a slight decrease in numbers of children and adolescents lead to a reduction in deaths from CMPN in the trend and target scenarios. In all scenarios, NCD deaths rise with the rising population; however, the number of deaths is much smaller in the target scenario. The share of CMPN in total deaths declines from 26.0% in 2015 to 23.0%, 17.6%, and 19.1% in 2030 under the status quo, trend, and target scenario, respectively. On the other hand, the contribution of the four major NCDs (CVD, respiratory diseases, diabetes, and neoplasms) in total deaths increases from 54.9% in 2015 to 58.9%, 63.4%, and 60.2% in 2030 under the status quo, trend, and target scenarios, respectively.

[Figure 6 here]

Table 1 shows the number of deaths under the three mortality scenarios and the number of deaths averted under the target scenario compared to the status quo and trend. Of the four major NCDs, CVD is the major killer, followed by neoplasm, respiratory diseases, and diabetes. In 2025, the model projects 375 thousand, 357 thousand, and 334 thousand deaths from CVD under status quo, trend, and target, respectively, which entails 23 thousand and 41 thousand CVD deaths averted under the target scenario compared to trend and status quo scenarios. Over 2015 – 2030, the target scenario would avert a cumulative 485 thousand (285 thousand male and 199 thousand female) CVD deaths and 282 thousand CVD deaths (162 thousand male and 120 thousand female) compared to the status quo and trend scenario, respectively. Under the target scenario, the cumulative (2015- 2030) number of deaths averted from the four major NCDs is projected to be about 897 thousand (500 thousand male, 396 thousand female) and 596 thousand (291 thousand male, 305 thousand female), compared to the status quo and trend scenarios, respectively.

[Table 1 here]

The Supplementary Table S5 shows the projections of years of lives lost (YLL) in the three scenarios, and YLL averted in the target scenario compared to status quo and trend. Compared to the status quo mortality trajectories, the attainment of NCD targets would avert a cumulative (2015 – 2030) 14.9 million YYL (i.e., 7.74, 2.2, 0.49, and 4.49 million YLL averted form CVD, respiratory diseases, diabetes, and neoplasm respectively). Compared to the trend mortality trajectories, the attainment of NCD targets would avert a cumulative (2015 – 2030) 12.16 million YYL (i.e., 5.30, 0.92, 0.64, and 5.30 million YLL averted form CVD, respiratory diseases, diabetes, and neoplasm respectively).

Table 2 reports the projections for life expectancy, infant mortality, under-five mortality, and probability of premature deaths (i.e., between age 30-70) from NCDs. Male life expectancy at birth increases from 71.10 in 2015 to 73.47 and 74.38 years in 2030 under the trend and target scenario, respectively. Female life expectancy at birth increases from 73.68 years in 2015 to 75.34 and 76.39 in 2030 in the trend and target scenarios. Fulfillment of SDG NCD mortality targets entail 2.63 and 1.96 year increases in life expectancy at age 30 for male and female population, respectively (i.e., life expectancies at 30 in the target scenario: 43.79 years in 2015 vs. 46.42 years in 2030 for male; and 43.36 years in 2015 vs. 48.32 years in 2030 for female). The projections show declining trends for infant and child mortality in both trend and target scenarios. Since the drivers of infant and child mortality are primarily CMPN diseases, the magnitudes of reduction are similar in the trend and target scenarios. Large reductions in the probabilities of premature deaths (i.e., between age 30–70) are projected in both scenarios, and the reduction is much larger in the target scenario. The probability of death for male between age

30–70 from any of four major NCDs decreases from 219 per 1000 people in 2015 to 198 and 153 per 1000 people in 2030 in the trend and target scenarios, respectively. The probability of premature death for female from four major NCDs decreases from 199 per 1000 people in 2015 to 186 and 138 per 1000 people in 2030 in the trend and target scenarios, respectively. For the target scenario, these entail an overall 30% reduction in the probability of premature deaths from four major NCDs.

[Table 2 here]

Discussion

The cohort-component model in this study projects the demographic outlook of a population using a systems-dynamic process determined by interrelationships between population determinants, including those affected by policy actions.[2,17,29] The strengths of this model are several. First, it is replicable as it uses established principles about the dynamics of the population process. Second, it can produce consistent and comparable cross-country estimates that are easy to update using country data across multiple countries. Third, it can provide focused estimates for target groups of interest because it tracks population outcomes at a highly disaggregated level. In the same vein, the model can be flexibly adapted to the intended disaggregation schemes (e.g. more aggregate) of population cohorts and disease categories; Finally, the model outcomes can be potentially linked to other dynamic inputs related to health systems, education, the environment, housing and city planning, infrastructure, energy and utility, and alike.[29] The main contribution of the model used in this study is in estimating the expected demographic shifts associated with different disease-specific mortality trajectories. The resulting estimates inform the effects of proposed NCD control targets, linking the number of deaths averted by achieving these targets to demographic shifts in the population.[29]

The model in this study has several limitations. The cohort component method does not explicitly incorporate socio-economic determinants of population change. The evolution of fertility, mortality, and migration over time are not endogenously determined; the respective trajectories are set exogenously using informed assumptions. To that effect, the model outcomes are projections based on a set of assumptions about trajectories of mortality, fertility, and migration. The objective is not to make a perfect prediction of the future, but to assess comparative differences in population trajectories resulting from different health policy scenarios, keeping other input assumptions constant. Therefore, the model outcomes should not be interpreted as a perfect forecast but are based on conditional calculations showing what the future population would be if a particular set of reasonable assumptions were to hold true. Using similar assumptions but different approach, a global study by Cao et al. (2018) quantified the potential gains in average expected life-years lived between 30 years and 70 years of age worldwide should the SDG target of a one-third reduction in premature mortality from the four major NCDs be achieved, as well as the maximum gains if all premature mortality from these diseases was eliminated.[30] While the model in our paper captures differences in mortality scenarios, it does not capture the extent of disabilities averted from attaining the targets. Also, the scenarios do not consider the mortality implications of the recent covid-19 pandemic in Bangladesh.

The model generates the evolution of annual cohorts and population structure during 2015-2030 using demographic indicators for Bangladesh that are consistent with those offered by international agencies.[3,4,5] For instance, while the model replicates the baseline (2015) demographic indicators as reported in UN population projections, the population shares in 2030 for the 0-14, 15-64, and 65 and above years old age-groups in the UN medium variant projections vs the model trend projections compare as follow: 22.9 vs 23.8; 69.7 vs 68.8; and 7.4 vs 7.4, respectively. This model captures dynamic population outflows based on deaths from disaggregated disease categories, allowing comparison between disease-specific mortality scenarios. We estimated that by attaining NCD targets in compliance with SDG 2030 goals, people in Bangladesh will live longer by more than 3 years on average (3.27 and 2.71 years for males and females, respectively). Over the 15-year analysis period, a cumulative 1.73 million all-cause deaths (99.6 thousand male and 73.6 thousand female) and 584 thousand all-cause deaths (284 thousand male and 300 thousand female) would be averted in the NCD target scenario compared to the status quo and trend scenarios, respectively. In the target scenario, the cumulative number of deaths averted from the four major NCDs are projected to be 896 thousand (500 thousand male, 396 thousand female) and 597 thousand (291 thousand male, 305 thousand female), compared to the status quo and trend scenarios, respectively. These estimates inform the potential benefits as well as trade-offs in health and demographic outcomes associated with accomplishing current NCD targets.

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Author Contribution: Muhammad Jami Husain conceptualized the study, implemented the methodology, developed the modeling framework in the Vensim software, acquired data, and led the formal analysis and write-up. Biplab Datta contributed to the study plan and analysis, model development, interpretation of results and critical review of the paper. Deliana Kostova contributed to the study plan and analysis, interpretation of results and critical review of the paper. All authors critically reviewed the manuscript and approved the final version.

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Table 1: Number of deaths and deaths averted from 4 major NCDs

	Deaths and deaths averted in 2025			Deaths and deaths averted in 2030			Cumulative number of deaths and deaths averted: 2015 - 2030		
	Male	**Female**	**Total**	**Male**	**Female**	**Total**	**Male**	**Female**	**Total**
Cardiovascular Diseases									
Number of Deaths									
Status quo	189239	185322	374561	212078	201626	413704	2790691	2701365	5492056
Trend	178532	178423	356955	197107	191310	388417	2667253	2621899	5289152
NCD target	165118	168569	333687	174039	173421	347460	2505477	2502029	5007506
Deaths averted in NCD target scenario									
Compared to status quo	24121	16753	40874	38039	28205	66244	285214	199336	484550
Compared to trend	13414	9854	23268	23068	17889	40957	161776	119870	281646
Respiratory Diseases									
Number of Deaths									
Status quo	67761	52218	119980	75691	56609	132300	998798	761490	1760288
Trend	60586	49204	109789	64545	51640	116185	914259	725901	1640160
NCD target	58953	46487	105439	61818	46678	108496	894714	692819	1587533
Deaths averted in NCD target scenario									
Compared to status quo	8809	5732	14540	13873	9931	23804	104084	68670	172755
Compared to trend	1633	2717	4350	2727	4962	7689	19545	33082	52627
Diabetes									
Number of Deaths									
Status quo	16036	24649	40685	17809	26248	44056	236911	360091	597002
Trend	15686	25412	41097	17613	28072	45685	233429	370221	603650
NCD target	14858	23602	38460	16199	24798	40997	223476	348223	571698
Deaths averted in NCD target scenario									
Compared to status quo	1178	1047	2225	1610	1450	3060	13436	11868	25303
Compared to trend	828	1809	2637	1414	3274	4689	9954	21998	31952
Neoplasm									
Number of Deaths									
Status quo	75367	63763	139129	83959	72006	155965	1116473	937279	2053752
Trend	75386	64846	140232	85322	74376	159698	1119111	951193	2070304
NCD target	67086	54086	121172	71225	55565	126789	1019066	820728	1839794
Deaths averted in NCD target scenario									
Compared to status quo	8281	9676	17957	12735	16441	29176	97407	116551	213958
Compared to trend	8300	10759	19060	14098	18811	32909	100045	130465	230510

Note: Calculations derived from the model.

Table 2: Life expectancy, Infant mortality rate, Under-five mortality, Probability of dying age 0-70

	2015	2020	2025	2030	2015	2020	2025	2030
	Male				Female			
Life expectancy at birth								
Status quo	71.10	71.10	71.10	71.10	73.68	73.68	73.68	73.68
Trend	71.10	71.86	72.65	73.47	73.68	74.23	74.78	75.34
NCD target	71.10	72.14	73.23	74.38	73.68	74.56	75.46	76.39
Life expectancy at age 30								
Status quo	43.79	43.79	43.79	43.79	46.36	46.36	46.36	46.36
Trend	43.79	44.33	44.89	45.48	46.36	46.65	46.95	47.25
NCD target	43.79	44.62	45.49	46.42	46.36	47.00	47.65	48.32
Life expectancy at age 65								
Status quo	14.56	14.56	14.56	14.56	15.87	15.87	15.87	15.87
Trend	14.56	14.87	15.20	15.55	15.87	16.02	16.18	16.34
NCD target	14.56	14.95	15.36	15.79	15.87	16.12	16.37	16.63
Infant mortality rate								
Status quo	31.24	31.24	31.24	31.24	27.79	27.79	27.79	27.79
Trend	31.24	27.88	24.52	21.14	27.79	24.79	21.78	18.77
NCD target	31.24	27.88	24.52	21.14	27.79	24.79	21.78	18.77
Under-five mortality rate								
Status quo	38.16	38.16	38.16	38.16	34.54	34.54	34.54	34.54
Trend	38.16	34.05	29.92	25.79	34.54	30.81	27.06	23.31
NCD target	38.16	34.05	29.92	25.79	34.54	30.81	27.06	23.31
Probability of dying between age 30-70 from any of CVDs, respiratory diseases, diabetes, and cancer (per 1000 people)								
Status quo	219.0	219.0	219.0	219.0	199.3	199.3	199.3	199.3
Trend	219.0	211.9	204.8	197.6	199.3	194.9	190.4	186.0
NCD target	219.0	197.5	175.3	152.6	199.3	179.5	159.2	138.3
Probability of dying between age 30-70 from cardiovascular diseases (CVDs) (per 1000 people)								
Status quo	130.7	130.7	130.7	130.7	110.6	110.6	110.6	110.6
Trend	130.7	126.2	121.8	117.3	110.6	106.6	102.5	98.5
NCD target	130.7	117.2	103.5	89.6	110.6	99.1	87.4	75.5
Probability of dying between age 30-70 from respiratory diseases (per 1000 people)								
Status quo	36.9	36.9	36.9	36.9	31.1	31.1	31.1	31.1
Trend	36.9	34.3	31.7	29.1	31.1	30.0	28.9	27.8
NCD target	36.9	32.9	28.9	24.9	31.1	27.7	24.3	20.9
Probability of dying between age 30-70 from diabetes (per 1000 people)								
Status quo	7.8	7.8	7.8	7.8	12.0	12.0	12.0	12.0
Trend	7.8	7.6	7.4	7.2	12.0	12.1	12.2	12.4
NCD target	7.8	7.0	6.1	5.3	12.0	10.7	9.3	8.0
Probability of dying between age 30-70 from neoplasms (per 1000 people)								
Status quo	59.7	59.7	59.7	59.7	59.5	59.5	59.5	59.5
Trend	59.7	58.8	57.9	57.0	59.5	59.6	59.6	59.6
NCD target	59.7	53.3	46.9	40.4	59.5	53.2	46.8	40.3

Note: Calculations derived from the model.

Figure 1: Overview of the cohort-component population model: stock, flows, and simulation options*

Note: *The model is developed using the Vensim DSS (version 8) simulation platform. **dr**: death rate. **cmpn**: communicable, maternal, perinatal and nutritional conditions; **cvd**: Cardiovascular diseases; **rsp**: Respiratory diseases; **dbt**: Diabetes mellitus; **npl**: neoplasms; **oth**: Other NCDs and Injuries.

Figure 2: Population outlook for Bangladesh: 2015 – 2030 (M: Million)
Note: Calculations derived from the model.

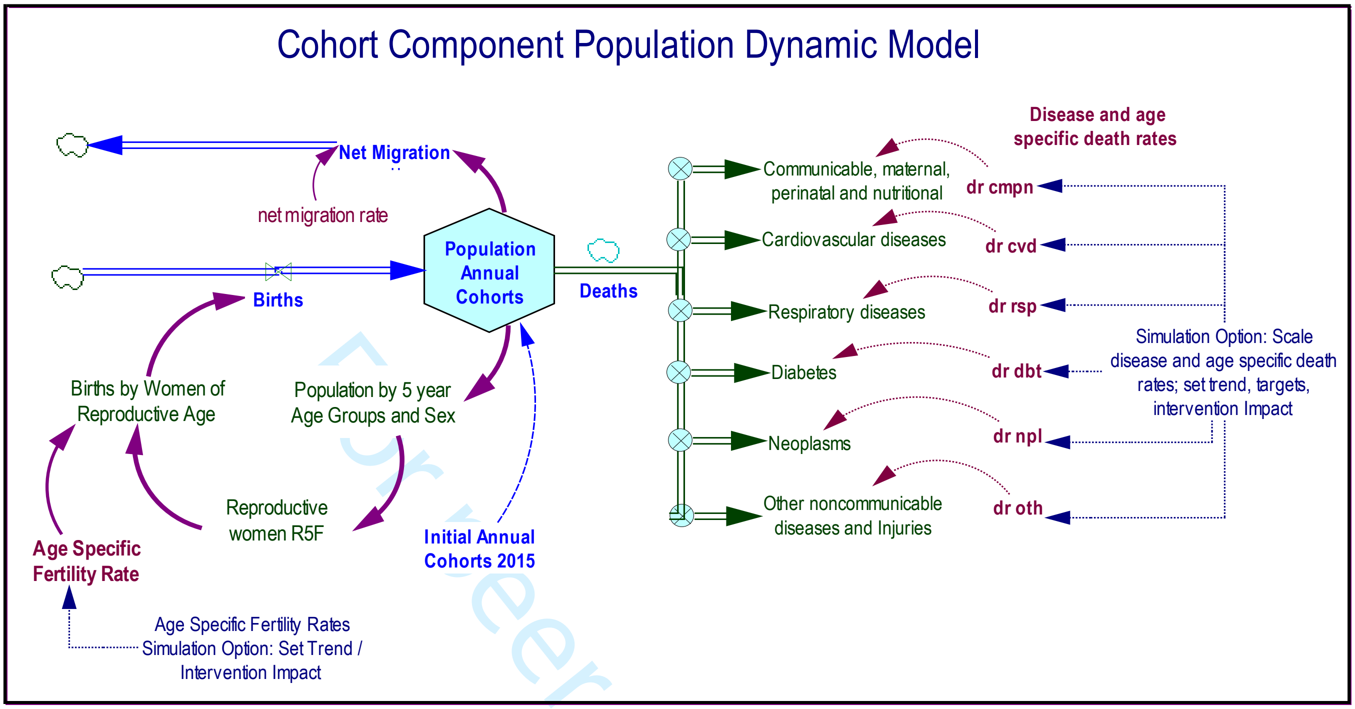
Figure 3: Projected Population age structure in Bangladesh: 2015 and 2030
Note: Calculations derived from the model.

Figure 4: Child, old-age, and total dependency ratios
Note: Calculations derived from the model.

Figure 5: Number of women in reproductive age (15 – 49 years)
Note: Calculations derived from the model.

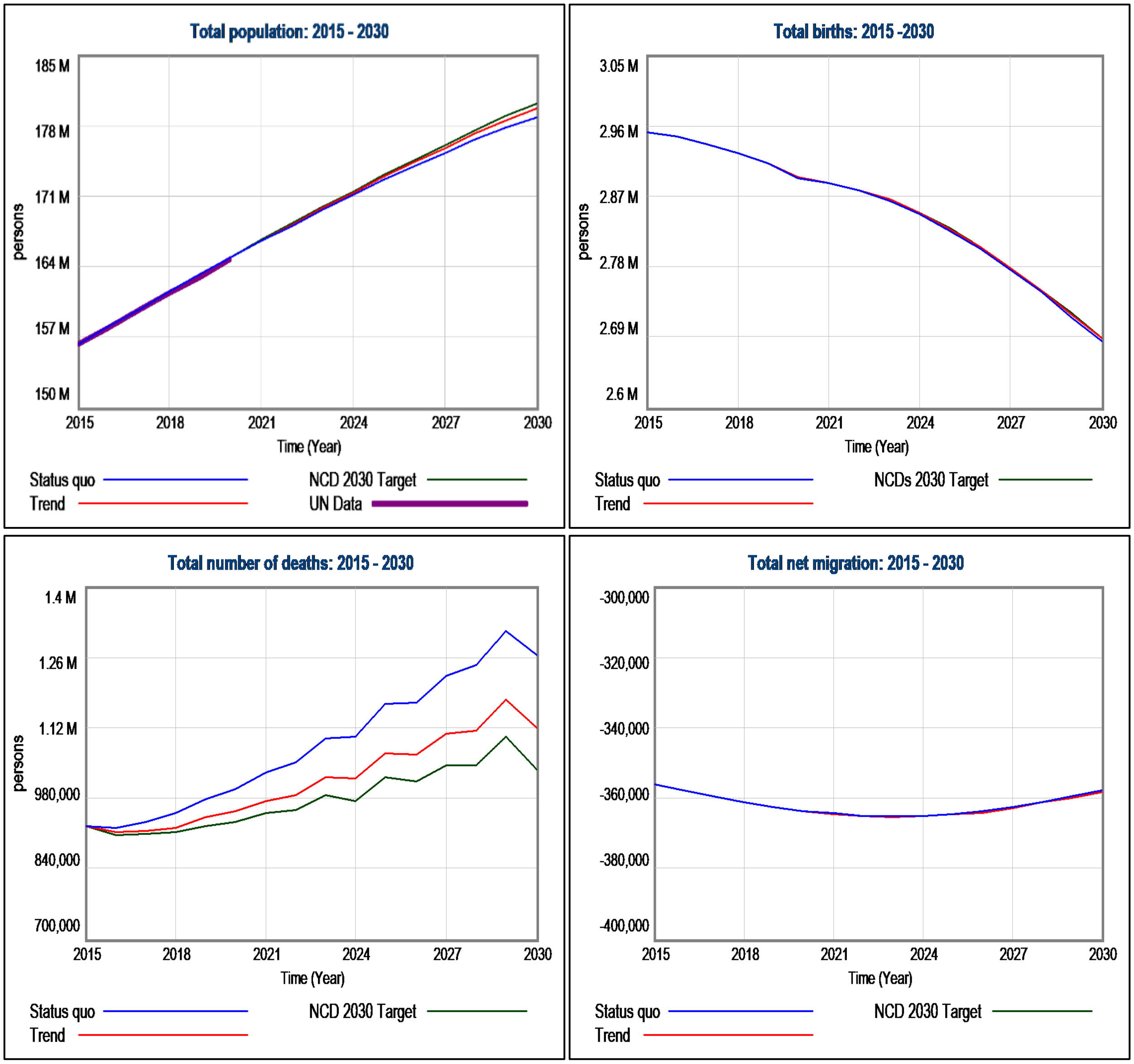
Figure 6: Mortality by diseases
Note: Calculations derived from the model.

Figure 1: Overview of the cohort-component population model: stock, flows, and simulation options*



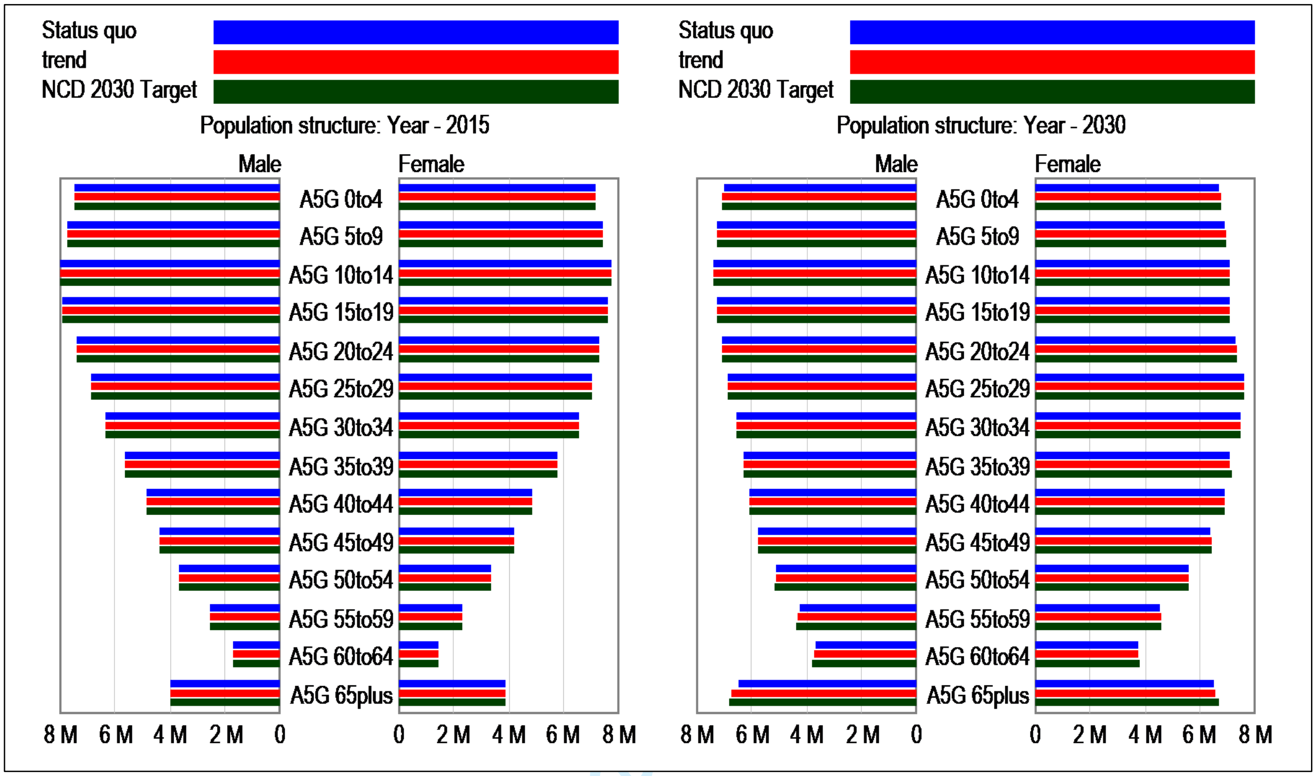
Note: *The model is developed using the Vensim DSS (version 8) simulation platform. **dr**: death rate. **cmpn**: communicable, maternal, perinatal, and nutritional conditions; **cvd**: Cardiovascular diseases; **rsp**: Respiratory diseases; **dbt**: Diabetes mellitus; **npl**: neoplasms; **oth**: Other NCDs and Injuries.

Figure 2: **Population outlook for Bangladesh: 2015 – 2030 (M: Million)**



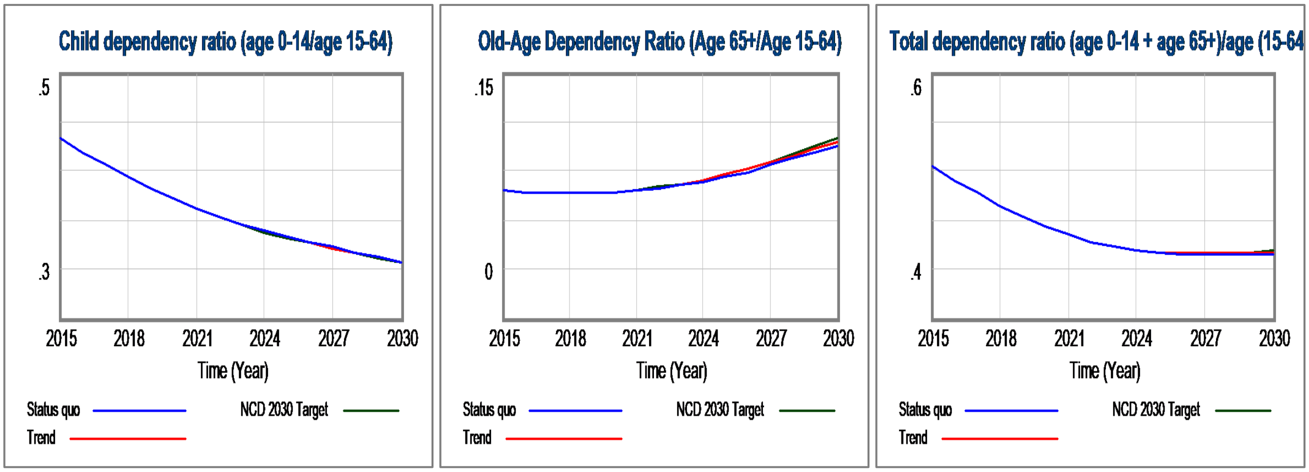
Note: Calculations derived from the model.

Figure 3: **Projected Population age structure in Bangladesh: 2015 and 2030**



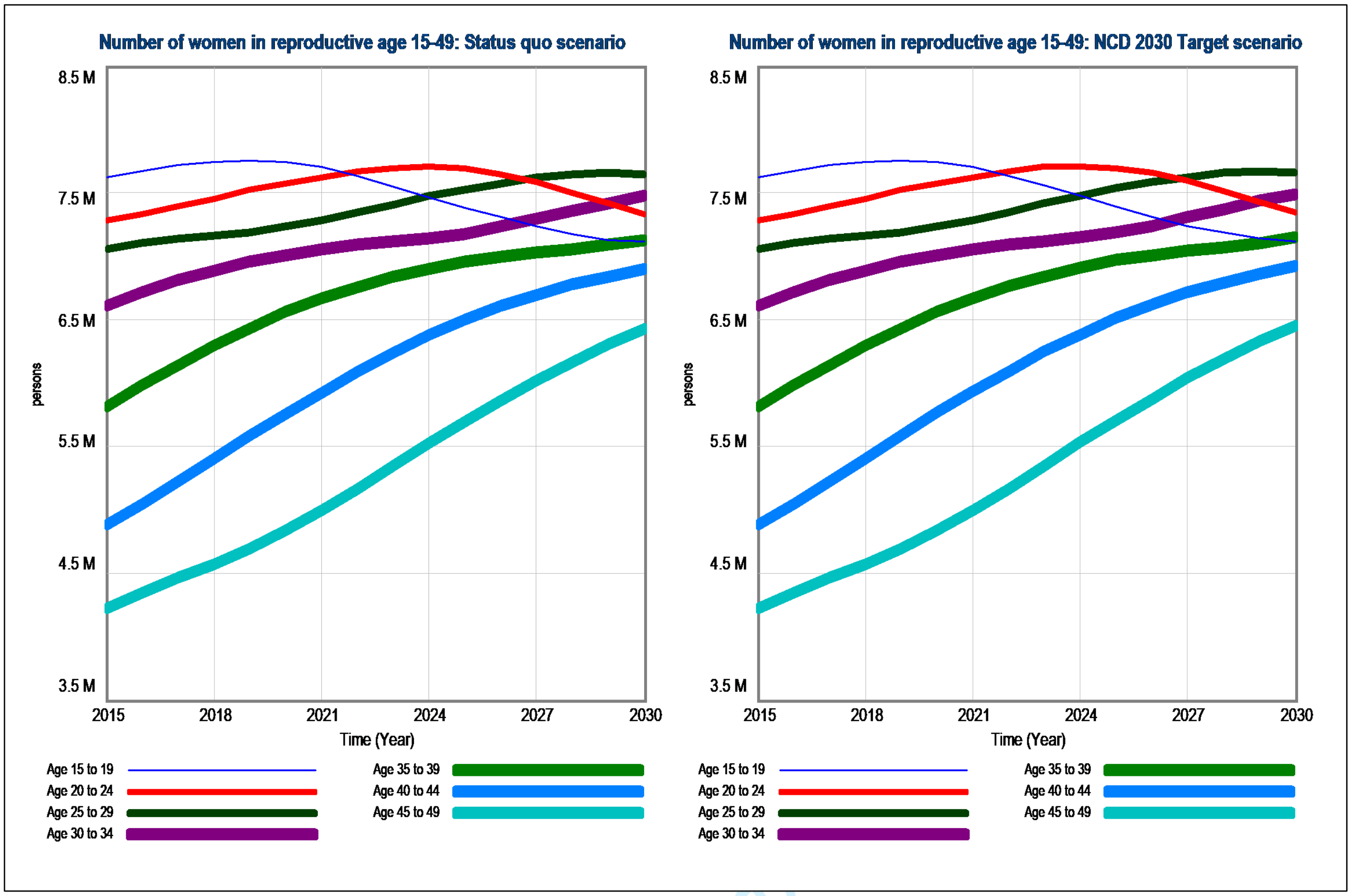
Note: Calculations derived from the model. A5G refers to 5-year age groups.

Figure 4: **Child, old-age, and total dependency ratios**



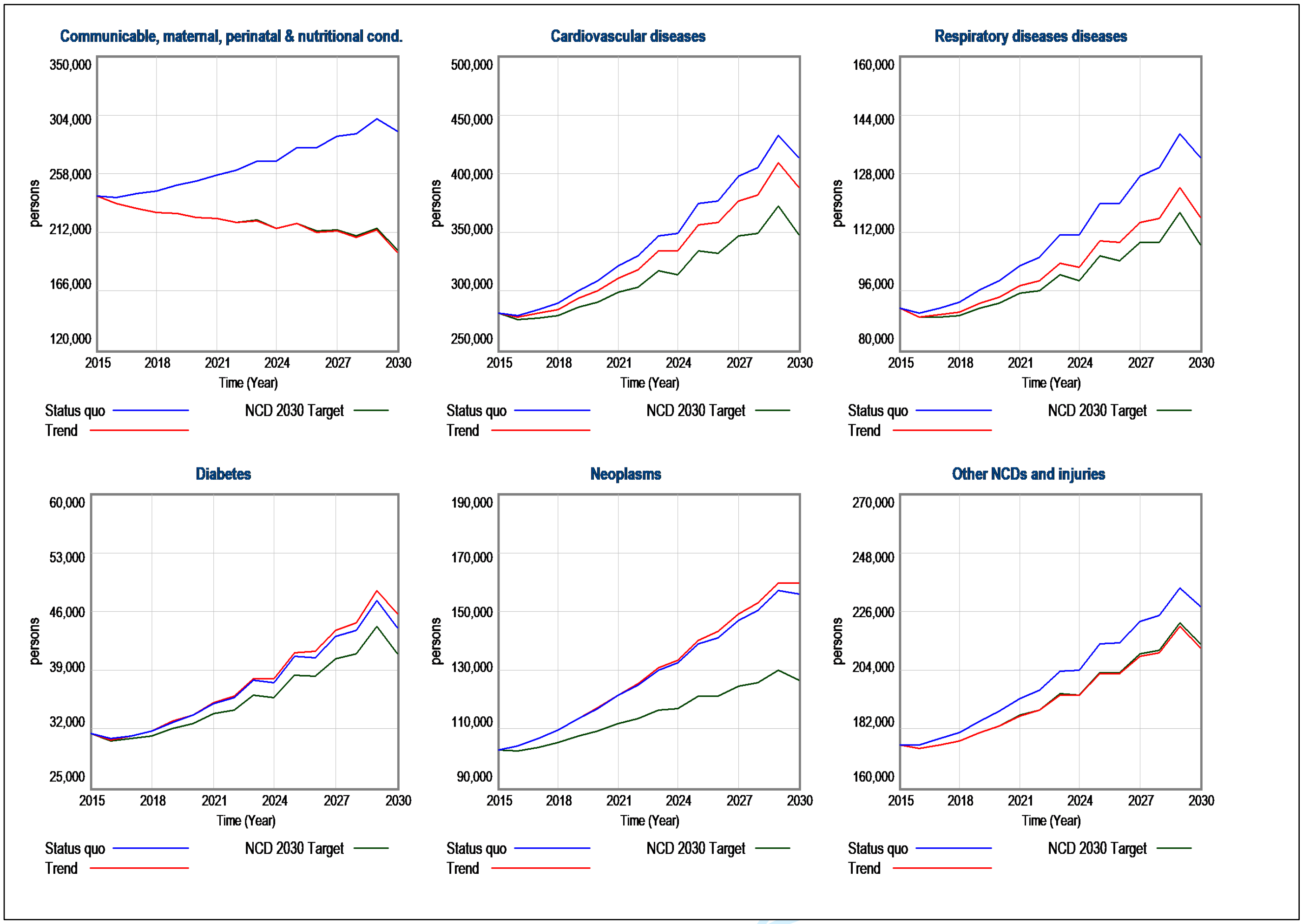
Note: Calculations derived from the model.

Figure 5: Number of women in reproductive age (15 – 49 years)



Note: Calculations derived from the model.

Figure 6: **Mortality by diseases**



Note: Calculations derived from the model.

Supplementary Table S1: Mapping of disease categories

Broad groups	WHO GHE Code	GHE Cause name*
Communicable, maternal, perinatal and nutritional conditions	I.A. Infectious and parasitic diseases	(1-12): Tuberculosis; STDs excluding HIV; HIV/AIDS; Diarrhoeal diseases; Childhood-cluster diseases; Meningitis; Encephalitis; Hepatitis; Parasitic and vector diseases; Intestinal nematode infections; Leprosy; Other infectious diseases
	I.B. Respiratory Infectious	(1-3): Lower respiratory infections; Upper respiratory infections; Otitis media
	I.C. Maternal conditions	
	I.D. Neonatal conditions	(1-4): Preterm birth complications; Birth asphyxia and birth trauma; Neonatal sepsis and infections; Other neonatal conditions
	I.E. Nutritional deficiencies	(1-5): Protein-energy malnutrition; Iodine deficiency; Vitamin A deficiency; Iron-deficiency anaemia; Other nutritional deficiencies
Neoplasms	II.A. Malignant neoplasms	(1-24): Mouth and oropharynx cancers; Oesophagus cancer; Stomach cancer; Colon and rectum cancers; Liver cancer; Pancreas cancer; Trachea, bronchus, lung cancers; Melanoma and other skin cancers; Breast cancer; Cervix uteri cancer; Corpus uteri; cancer; Ovary cancer; Prostate cancer; Testicular cancer; Kidney cancer; Bladder cancer; Brain and nervous system cancers; Gallbladder and biliary tract cancer; Larynx cancer; Thyroid cancer; Mesothelioma; Lymphomas, multiple myeloma; Leukaemia; Other malignant neoplasms
	II.B. Other neoplasms	
Diabetes	II.C. Diabetes mellitus	
Cardiovascular diseases	II. H. Cardiovascular diseases	(1-6): Rheumatic heart disease; Hypertensive heart disease; Ischaemic heart disease; Stroke; Cardiomyopathy, myocarditis, endocarditis; Other circulatory diseases
Respiratory diseases	II.I. Respiratory diseases	(1-3): Chronic obstructive pulmonary disease; Asthma; Other respiratory diseases
Other NCDs and Injuries	II.D. Endocrine, blood, immune disorders	(1-4): Thalassaemias; Sickle cell disorders and trait; Other haemoglobinopathies and haemolytic anaemias; Other endocrine, blood and immune disorders
	II.E. Mental and substance use disorders	(1-11): Depressive disorders; Bipolar disorder; Schizophrenia; Alcohol use disorders; Drug use disorders; Anxiety disorders; Eating disorders; Autism and Asperger syndrome; Childhood behavioural disorders; Idiopathic intellectual disability; Other mental and behavioural disorders
	II.F. Neurological conditions	(1-7): Alzheimer disease and other dementias; Parkinson disease; Epilepsy; Multiple sclerosis; Migraine; Non-migraine headache; Other neurological conditions
	II. J. Digestive diseases	(1-9): Peptic ulcer disease; Cirrhosis of the liver; Appendicitis; Gastritis and duodenitis; Paralytic ileus and intestinal obstruction; Inflammatory bowel disease; Gallbladder and biliary diseases; Pancreatitis; Other digestive diseases
	II.K. Genitourinary diseases	(1-6): Kidney diseases; Benign prostatic hyperplasia; Urolithiasis; Other urinary diseases; Infertility; Gynecological diseases
	II.L. Skin diseases	
	II.M. Musculoskeletal diseases	(1-5): Rheumatoid arthritis; Osteoarthritis; Gout; Back and neck pain; Other musculoskeletal disorders
	II.N. Congenital anomalies	(1-6): Neural tube defects; Cleft lip and cleft palate; Down syndrome; Congenital heart anomalies; Other chromosomal anomalies; Other congenital anomalies
	II.O: Oral conditions	
	II.P. Sudden infant death syndrome	
	III.A. Unintentional injuries	(1-8): Road injury; Poisonings; Falls; Fire, heat and hot substances; Drowning Exposure to mechanical forces; Natural disasters; Other unintentional injuries
	III.B. Intentional injuries	(1-3): Self-harm; Interpersonal violence; Collective violence and legal intervention

Note: * See Annex Table A in: World Health Organization. (2018). WHO methods and data sources for global burden of disease estimates 2000-2016. *Global Health Estimates Technical Paper WHO/HIS/IER/GHE/2018.4, WHO, Geneva*.

Supplementary Table S2: Demographic Indicators

Indicators	Description
Annual population	Annual population by sex and annual cohorts (age 0 – 100+), by age-groups
Annual population age structure	Population and share of total population by five-year age groups – by sex; Five-year age-groups: age 0 – 4, age 5 – 9, age 10 – 14, age 15 – 19, age 20 – 24, age 25 – 29, age 30 – 34, age 35 – 39, age 40 – 44, age 45 – 49, age 50 – 54, age 55 – 59, age 60 – 64, age 65 and above.
Total, child, and old-age dependency ratios	(i) Total Dependency Ratio ((Age 0-14 + Age 65+) / Age 15-64); (ii) Total Dependency Ratio ((Age 0-19 + Age 65+) / Age 20-64); (iii) Child Dependency Ratio (Age 0-14 / Age 15-64); (iv) Child Dependency Ratio (Age 0-19 / Age 20-64); (v) Old-Age Dependency Ratio (Age 65+ / Age 15-64); (vi) Old-Age Dependency Ratio (Age 65+ / Age 20-64)
Number of births	Annual number of births by sex
Crude birth rate	Average annual number of births per 1,000 population.
Age-specific fertility rate	Number of births to women in a particular age group, divided by the number of women in that age group. The age groups used are: 15-19, 20-24, ..., 45-49.
Total fertility	The average number of live births a cohort of women would have at the end of their reproductive period if they were subject during their whole lives to the fertility rates of a given period and if they were not subject to mortality. It is expressed as live births per woman.
Net reproduction rate	The average number of daughters a cohort of women would have at the end of their reproductive period if they were subject during their whole lives to the fertility rates and the mortality rates of a given period. It is expressed as number of daughters per woman.
Rate of natural population increase	The difference between the number of live births and the number of deaths occurring in a year, divided by the population of that year, multiplied by a factor (usually 1,000). It is equal to the difference between the crude birth rate and the crude death rate.
Crude death rate	Average annual number of deaths per 1,000 population.
Number of deaths	Total annual number of deaths, by sex and annual cohorts.
Death rate or mortality rate	A measure of the number of deaths (in general, or due to a specific cause) in a population, scaled to the size of that population, per unit of time (e.g. the number of deaths per one thousand people per year).
Deaths by diseases	Total annual number of deaths; by sex and annual cohorts; by six broad disease categories: communicable, maternal, perinatal and nutritional conditions; neoplasms; diabetes; cardiovascular diseases; respiratory diseases; other noncommunicable diseases and Injuries.
Infant mortality rate	Probability of dying between birth and exact age 1; expressed as average annual deaths per 1,000 births.
Under-five mortality rate	Probability of dying between birth and age 5; expressed as average annual deaths per 1,000 births.
Probabilities of dying between age 30 to 70 from major NCDs	Per 1000 of 30-year-old-people who would die before their 70th birthday from any of cardiovascular disease, cancer, diabetes, or chronic respiratory disease, assuming that s/he would experience current mortality rates at every age and s/he would not die from any other cause of death.
Life expectancy at birth	The average number of years that a newborn could expect to live if he or she were to pass through life exposed to the sex- and age-specific death rates prevailing at the time of his or her birth, for a specific year, in a given country.
Life expectancy at age *'x'* years	The average number of years that a person of *'x'* years of age could expect to live if exposed to the sex- and age-specific death rates prevailing at the time of his/her X_{th} birthday
Crude net migration rate:	The ratio of net migration during the year to the average population in that year. The value is expressed per 1 000 inhabitants.
Total net migration	Number of migrants, that is, the number of immigrants minus the number of emigrants.
Years of lives lost	The years of potential life lost due to premature deaths calculated by summing up number of deaths at each age multiplied by life expectancy at the age at which death occurs

Source: United Nations, Department of Economic and Social Affairs, Population Division (2013). World Population Prospects: The 2012 Revision.

Supplementary Table S3: Baseline data for 2015

Age	Fertility rate		Death rate: Total		Death rate: CMPN		Death rate: CVD		Death rate: DBT		Death rate: RSP		Death rate: NPL		Death rate: OTH		Net migration rate	
	Per 1000 women		Per 1000 people															
	Data	Calib.*	M**	F**	M	F	M	F	M	F	M	F	M	F	M	F	M	F
< 1 years			31.74	28.18	24.92	22.13	0.12	0.11	0.01	0.01	0.06	0.10	0.31	0.33	6.34	5.50	0.00	0.00
1 – 4 years			1.73	1.69	1.36	1.33	0.01	0.01	0.00	0.00	0.00	0.01	0.02	0.02	0.35	0.33	0.00	0.00
5 - 9 years			0.55	0.66	0.20	0.35	0.01	0.02	0.00	0.00	0.00	0.01	0.03	0.03	0.30	0.25	0.29	0.16
10 – 14 years			0.53	0.52	0.20	0.27	0.01	0.01	0.00	0.00	0.00	0.01	0.03	0.02	0.29	0.20	0.83	0.20
15 - 19 years	75	77	0.83	0.86	0.16	0.30	0.07	0.08	0.00	0.01	0.01	0.03	0.05	0.06	0.53	0.38	-6.17	-0.24
20 – 24 years	137	140	0.94	0.88	0.18	0.31	0.08	0.08	0.00	0.01	0.02	0.03	0.06	0.06	0.61	0.39	-16.49	-0.54
25 – 29 years	105	105	1.06	1.06	0.20	0.37	0.09	0.10	0.00	0.01	0.02	0.04	0.07	0.08	0.68	0.47	-11.70	-0.19
30 - 34 years	56	56	1.33	1.30	0.31	0.25	0.34	0.28	0.02	0.03	0.05	0.06	0.21	0.41	0.41	0.26	-7.46	-0.19
35 - 39 years	25	25	1.79	1.65	0.41	0.32	0.45	0.36	0.02	0.04	0.06	0.08	0.28	0.52	0.56	0.33	-6.12	0.01
40 - 44 years	9	9	2.81	2.09	0.65	0.41	0.71	0.45	0.03	0.05	0.10	0.10	0.44	0.66	0.88	0.41	-3.63	0.16
45 - 49 years	3	3	4.53	2.76	1.04	0.54	1.15	0.60	0.05	0.07	0.16	0.13	0.72	0.88	1.41	0.54	-1.74	0.16
50 – 54 years			8.33	5.01	1.58	0.51	2.84	1.55	0.12	0.16	0.56	0.37	1.61	1.71	1.60	0.72	-0.34	0.14
55 – 59 years			11.39	8.29	2.17	0.84	3.89	2.56	0.17	0.26	0.77	0.62	2.21	2.83	2.19	1.19	-0.13	0.12
60 – 64 years			22.99	16.37	4.13	1.54	8.92	7.55	0.55	0.77	2.79	2.12	3.28	2.26	3.32	2.13	-0.04	0.07
65 – 69 years			27.91	24.38	5.01	2.30	10.83	11.25	0.67	1.14	3.38	3.15	3.98	3.37	4.03	3.17	0.21	0.06
70 – 74 years			56.59	45.38	12.57	7.03	18.84	20.16	2.22	3.09	8.94	5.87	5.80	2.27	8.22	6.96	0.21	0.06
75 – 79 years			60.00	46.35	13.33	7.18	19.97	20.59	2.36	3.16	9.48	6.00	6.14	2.31	8.72	7.11	0.21	0.06
80 – 84 years			90.37	71.99	20.07	11.16	30.08	31.98	3.55	4.90	14.28	9.32	9.25	3.59	13.13	11.04	0.21	0.06
85 year			151.53	125.05	33.66	19.38	50.44	55.55	5.95	8.52	23.94	16.18	15.52	6.24	22.02	19.17	0.21	0.06
90 year			434.35	416.70	96.49	64.59	144.59	185.11	17.05	28.38	68.63	53.92	44.48	20.81	63.12	63.89	0.21	0.06
95 year			717.18	708.35	159.31	109.79	238.73	314.67	28.16	48.25	113.32	91.67	73.45	35.37	104.22	108.60	0.21	0.06
100 and above			1000	1000	222.1	155.00	332.88	444.24	39.26	68.12	158.00	129.41	102.41	49.93	145.31	153.32	0.21	0.06

Note: * 2015 age-group specific fertility data obtained from the Bangladesh Burau of Statistics produced total fertility rate of 2.05; the data has been calibrated up to produce a total fertility rate of 2.10 for 2015. ** **M:** Male; **F:** Female. The numbers are rounded to two decimal points.

Supplementary Table S4: The scale factors ($I^{\delta}_{s,A,d,t}$) for the 'trend' and 'NCD target' mortality rate trajectories

Age	Scenario	Male			Female			Male			Female		
		2015	2020	2030	2015	2020	2030	2015	2020	2030	2015	2020	2030
		Infectious, Maternal, Perinatal, Nutritional						**Cardiovascular Disease**					
Age 0-4	*Trend*	1.000	0.869	0.608	1.000	0.867	0.602	1.000	0.955	0.866	1.000	0.931	0.794
	Target	1.000	0.869	0.608	1.000	0.867	0.602	1.000	0.955	0.866	1.000	0.931	0.794
Age 5-14	*Trend*	1.000	0.849	0.547	1.000	0.848	0.544	1.000	0.972	0.915	1.000	0.961	0.882
	Target	1.000	0.849	0.547	1.000	0.848	0.544	1.000	0.972	0.915	1.000	0.961	0.882
Age 15-29	*Trend*	1.000	0.842	0.526	1.000	0.850	0.549	1.000	0.924	0.771	1.000	0.929	0.788
	Target	1.000	0.842	0.526	1.000	0.850	0.549	1.000	0.924	0.771	1.000	0.929	0.788
Age 30-49	*Trend*	1.000	0.842	0.525	1.000	0.848	0.544	1.000	0.948	0.845	1.000	0.940	0.821
	Target	1.000	0.842	0.525	1.000	0.848	0.544	1.000	0.948	0.670	1.000	0.940	0.670
Age 50-69	*Trend*	1.000	0.871	0.612	1.000	0.889	0.666	1.000	0.965	0.895	1.000	0.963	0.889
	Target	1.000	0.871	0.612	1.000	0.889	0.666	1.000	0.965	0.670	1.000	0.963	0.670
Age 70+	*Trend*	1.000	0.923	0.769	1.000	0.931	0.792	1.000	0.963	0.888	1.000	0.989	0.966
	Target	1.000	0.923	0.769	1.000	0.931	0.792	1.000	0.963	0.888	1.000	0.989	0.966
		Respiratory Disease						**Neoplasm**					
Age 0-4	*Trend*	1.000	0.947	0.842	1.000	0.915	0.746	1.000	1.040	1.119	1.000	1.036	1.107
	Target	1.000	0.947	0.842	1.000	0.915	0.746	1.000	1.040	1.119	1.000	1.036	1.107
Age 5-14	*Trend*	1.000	0.954	0.863	1.000	0.932	0.797	1.000	0.987	0.960	1.000	0.992	0.975
	Target	1.000	0.954	0.863	1.000	0.932	0.797	1.000	0.987	0.960	1.000	0.992	0.975
Age 15-29	*Trend*	1.000	0.912	0.737	1.000	0.918	0.755	1.000	0.989	0.967	1.000	0.987	0.960
	Target	1.000	0.912	0.737	1.000	0.918	0.755	1.000	0.989	0.967	1.000	0.987	0.960
Age 30-49	*Trend*	1.000	0.910	0.731	1.000	0.945	0.836	1.000	0.983	0.950	1.000	1.005	1.014
	Target	1.000	0.910	0.670	1.000	0.945	0.670	1.000	0.983	0.670	1.000	1.005	0.670
Age 50-69	*Trend*	1.000	0.929	0.788	1.000	0.966	0.897	1.000	0.984	0.953	1.000	0.999	0.998
	Target	1.000	0.929	0.670	1.000	0.966	0.670	1.000	0.984	0.670	1.000	0.999	0.670
Age 70+	*Trend*	1.000	0.940	0.820	1.000	0.969	0.907	1.000	1.004	1.012	1.000	1.029	1.086
	Target	1.000	0.940	0.820	1.000	0.969	0.907	1.000	1.004	1.012	1.000	1.029	1.086
		Diabetes						**Other NCDs and Injuries**					
Age 0-4	*Trend*	1.000	0.981	0.942	1.000	0.988	0.964	1.000	0.967	0.902	1.000	0.975	0.925
	Target	1.000	0.981	0.942	1.000	0.988	0.964	1.000	0.967	0.902	1.000	0.975	0.925
Age 5-14	*Trend*	1.000	0.982	0.947	1.000	0.966	0.898	1.000	0.971	0.914	1.000	0.974	0.923
	Target	1.000	0.982	0.947	1.000	0.966	0.898	1.000	0.971	0.914	1.000	0.974	0.923
Age 15-29	*Trend*	1.000	0.931	0.793	1.000	0.953	0.860	1.000	0.963	0.888	1.000	0.942	0.827
	Target	1.000	0.931	0.793	1.000	0.953	0.860	1.000	0.963	0.888	1.000	0.942	0.827
Age 30-49	*Trend*	1.000	0.961	0.883	1.000	1.010	1.030	1.000	0.953	0.859	1.000	0.953	0.859
	Target	1.000	0.961	0.670	1.000	1.010	0.670	1.000	0.953	0.859	1.000	0.953	0.859
Age 50-69	*Trend*	1.000	0.975	0.925	1.000	1.011	1.034	1.000	0.963	0.890	1.000	0.970	0.911
	Target	1.000	0.975	0.670	1.000	1.011	0.670	1.000	0.963	0.890	1.000	0.970	0.911
Age 70+	*Trend*	1.000	0.979	0.936	1.000	1.010	1.031	1.000	0.975	0.926	1.000	0.987	0.961
	Target	1.000	0.979	0.936	1.000	1.010	1.031	1.000	0.975	0.926	1.000	0.987	0.961

Note: The 'trend' scenario adopts sex, age-group and disease-specific mortality rate trajectories based on the latest WHO GHE regional mortality projections 2016-2030 for 'Southern Asia' consisting of Afghanistan, Bangladesh, Bhutan, India, Iran, Maldives, Nepal, Pakistan, and Sri Lanka. (WHO 2020, Mathers 2006)22,23 The scale factors in both the trend and the NCD 2030 target scenarios are same until 2020 for all age groups and disease categories. For the period 2021-2030, the scale factors used in the NCD target scenarios differ from the trend scenario for the age groups 30-49 and 50-69 for cardiovascular diseases, neoplasm, diabetes, and respiratory disease.

Supplementary Table S5: Years of lives lost (YLL) and YLL averted

	YLL and YLL averted in 2025			YLL and YLL averted in 2030			Cumulative number of YLL and YLL averted: 2015 - 2030		
	Male	**Female**	**Total**	**Male**	**Female**	**Total**	**Male**	**Female**	**Total**
Cardiovascular Diseases									
Years of lives lost (YLL)									
Status quo	2628410	2395870	5024280	2996780	2853440	5850220	39431070	35694730	75,125,800
Trend	2538880	2280630	4819510	2866200	2661530	5527730	38364420	34307980	72,672,400
NCD target	2289050	2094930	4383980	2428830	2320920	4749750	35338430	32042630	67,381,060
YLL averted in NCD target scenario									
Compared to status quo	339360	300940	640300	567950	532520	1100470	4092640	3652100	7,744,740
Compared to trend	249830	185700	435530	437370	340610	777980	3025990	2265350	5,291,340
Respiratory Diseases									
Years of lives lost (YLL)									
Status quo	749096	664638	1413734	873661	789733	1663394	11252806	9933068	21,185,874
Trend	683002	625524	1308526	762576	723793	1486369	10449656	9458391	19,908,047
NCD target	657731	575196	1232927	718066	630902	1348968	10143973	8843957	18,987,930
YLL averted in NCD target scenario									
Compared to status quo	91365	89442	180807	155595	158831	314426	1108833	1089111	2,197,944
Compared to trend	25271	50328	75599	44510	92891	137401	305683	614434	920,117
Diabetes									
Years of lives lost (YLL)									
Status quo	175112	286897	462009	203287	341275	544562	2642602	4303544	6,946,146
Trend	175277	298383	473660	205832	364177	570009	2647001	4447344	7,094,345
NCD target	159998	260900	420898	179167	296554	475721	2462325	3991308	6,453,633
YLL averted in NCD target scenario									
Compared to status quo	15114	25997	41111	24120	44721	68841	180277	312236	492,513
Compared to trend	15279	37483	52762	26665	67623	94288	184676	456036	640,712
Neoplasm									
Years of lives lost (YLL)									
Status quo	1280430	1492110	2772540	1422430	1682870	3105300	19346850	22311220	41,658,070
Trend	1308030	1529450	2837480	1479230	1750120	3229350	19693330	22768490	42,461,820
NCD target	1136680	1263360	2400040	1185180	1288140	2473320	17621820	19542930	37,164,750
YLL averted in NCD target scenario									
Compared to status quo	143750	228750	372500	237250	394730	631980	1725030	2768290	4,493,320
Compared to trend	171350	266090	437440	294050	461980	756030	2071510	3225560	5,297,070

Note: Calculations derived from the model.