Forecasting the effects of smoking prevalence scenarios on years of life lost and life expectancy from 2022 to 2050: a systematic analysis for the Global Burden of Disease Study 2021

*GBD 2021 Tobacco Forecasting Collaborators**

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Summary

Background Smoking is the leading behavioural risk factor for mortality globally, accounting for more than 175 million deaths and nearly 4·30 billion years of life lost (YLLs) from 1990 to 2021. The pace of decline in smoking prevalence has slowed in recent years for many countries, and although strategies have recently been proposed to achieve tobacco-free generations, none have been implemented to date. Assessing what could happen if current trends in smoking prevalence persist, and what could happen if additional smoking prevalence reductions occur, is important for communicating the effect of potential smoking policies.

Methods In this analysis, we use the Institute for Health Metrics and Evaluation's Future Health Scenarios platform to forecast the effects of three smoking prevalence scenarios on all-cause and cause-specific YLLs and life expectancy at birth until 2050. YLLs were computed for each scenario using the Global Burden of Disease Study 2021 reference life table and forecasts of cause-specific mortality under each scenario. The reference scenario forecasts what could occur if past smoking prevalence and other risk factor trends continue, the Tobacco Smoking Elimination as of 2023 (Elimination-2023) scenario quantifies the maximum potential future health benefits from assuming zero percent smoking prevalence from 2023 onwards, whereas the Tobacco Smoking Elimination by 2050 (Elimination-2050) scenario provides estimates for countries considering policies to steadily reduce smoking prevalence to 5%. Together, these scenarios underscore the magnitude of health benefits that could be reached by 2050 if countries take decisive action to eliminate smoking. The 95% uncertainty interval (UI) of estimates is based on the 2·5th and 97·5th percentile of draws that were carried through the multistage computational framework.

Findings Global age-standardised smoking prevalence was estimated to be 28·5% (95% UI 27·9–29·1) among males and 5·96% (5·76–6·21) among females in 2022. In the reference scenario, smoking prevalence declined by 25·9% (25·2–26·6) among males, and 30·0% (26·1–32·1) among females from 2022 to 2050. Under this scenario, we forecast a cumulative 29·3 billion (95% UI 26·8–32·4) overall YLLs among males and 22·2 billion (20·1–24·6) YLLs among females over this period. Life expectancy at birth under this scenario would increase from 73·6 years (95% UI 72·8–74·4) in 2022 to 78·3 years (75·9–80·3) in 2050. Under our Elimination-2023 scenario, we forecast 2·04 billion (95% UI 1·90–2·21) fewer cumulative YLLs by 2050 compared with the reference scenario, and life expectancy at birth would increase to 77·6 years (95% UI 75·1–79·6) among males and 81·0 years (78·5–83·1) among females. Under our Elimination-2050 scenario, we forecast 735 million (675–808) and 141 million (131–154) cumulative YLLs would be avoided among males and females, respectively. Life expectancy in 2050 would increase to 77·1 years (95% UI 74·6–79·0) among males and 80·8 years (78·3–82·9) among females.

Interpretation Existing tobacco policies must be maintained if smoking prevalence is to continue to decline as forecast by the reference scenario. In addition, substantial smoking-attributable burden can be avoided by accelerating the pace of smoking elimination. Implementation of new tobacco control policies are crucial in avoiding additional smoking-attributable burden in the coming decades and to ensure that the gains won over the past three decades are not lost.

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Introduction

Smoking has accounted for more than 175 million deaths globally over the past three decades.[1] Despite substantial progress in reducing smoking prevalence in many countries, smoking remains a leading risk factor for preventable morbidity and mortality.[2] More than one in ten global deaths and nearly 142 million years of life lost (YLLs) were attributable to smoking in 2021.[1] Smoking

Research in context

Evidence before this study

Smoking is widely recognised as a major global health risk with extensive supporting literature. The Global Burden of Diseases, Injuries, and Risk Factors Study serves as the most comprehensive source for smoking prevalence and all-cause and cause-specific attributable burden across 204 countries and territories, by age and sex. However, fewer studies have focused on forecasting tobacco use and burden. We searched PubMed on July 9, 2024, using the following search terms: ((“smok*”[All Fields] OR “tobacco”[All Fields]) AND (“forecast*”[All Fields] OR “scenario*”[All Fields] OR “projection*”[All Fields]) AND (“prevalence”[All Fields] OR “burden”[All Fields] OR “disease”[All Fields])). We restricted the search to articles published in the past 10 years. The search yielded 1098 studies. Many studies have forecasted smoking prevalence in the status quo, as well as under various policy scenarios, for specific countries. A 2024 WHO report forecasts global smoking prevalence will be 30·6% among males and 5·7% among females in 2030. Previous studies have also estimated future disease burden from smoking, although these studies typically focus on all causes combined or a small subset of smoking-related causes. Our search did not identify any studies that have estimated the future burden of smoking for all countries and all smoking-related health conditions.

Added value of this study

Our study contributes a comprehensive set of estimates of future health burden under three smoking prevalence scenarios for 204 countries and 365 diseases and injuries, disaggregated by 5-year age group and sex. Methodologically, we have developed a forecasting framework that incorporates smoking prevalence, intensity, duration, and risk reduction from cessation. Furthermore, by leveraging the Institute for Health Metrics and Evaluation’s Future Health Scenarios platform, our forecasts integrate dynamic changes in demographics and other determinants of health.

Implications of all the available evidence

The current evidence underscores the substantial potential for health gains through more aggressive tobacco control policies, worldwide. Although a continuation of the existing decline in smoking prevalence will undoubtedly yield health benefits, our analysis quantifies the substantial increase in life expectancy and decrease in years of life lost that could result from accelerated efforts in tobacco control.

also has important effects on health-care costs, productivity, and health disparities.[3–5] As a result, tobacco control is an enduring policy and public health priority, with enormous potential to improve population health.

After a period of accelerated progress following the adoption of WHO’s Framework Convention on Tobacco Control, progress has slowed in recent years.[6,7] Although global prevalence of smoking continues to decline, the pace of decline fluctuates and has slowed in many countries. Renewed efforts are required to overcome the tobacco industry’s attempts to maintain a market. The concept of a tobacco endgame, in which focus shifts from controlling the tobacco epidemic to eliminating the tobacco epidemic, has been discussed for more than 10 years in the academic literature.[8,9] Countries and organisations around the world have set goals to reduce smoking prevalence to less than 5% in the coming years.[10–13]

Strategies to reach a tobacco-free future work together to eliminate the initiation of tobacco use among youth while steadily phasing out tobacco use in the adult population. Despite promising policy proposals in some countries, including the UK,[14] the political commitment to implement and enforce the measures necessary to realise a tobacco-free future largely remains elusive. New Zealand’s transformational legislation that would have prohibited the sale of tobacco to anyone born on or after Jan 1, 2009, was recently repealed to fund other tax cuts. Similarly, Malaysia’s generational smoking ban was dropped from their recent tobacco control bill.[15,16] Forecasts of the health effects of potential smoking policy scenarios provide quantitative evidence on the costs of inaction that can aid decision makers.

Previous studies have simulated the effects of reducing smoking prevalence in selected countries.[17–29] These studies find large population health benefits that accrue over time, the potential for health-care cost savings, and reductions in smoking-attributable health disparities.[30,31] Although many prospective policy simulation studies exist for some countries, such analyses do not exist for all countries. Furthermore, previous studies have not systematically disaggregated impacts by disease, which can aid health system planning and prioritisation of medical innovation. Finally, health forecasting is a dynamic process that reflects simultaneous changes across many determinants of health and feedback between changes in health determinants and changes in demography. Our study adds to existing evidence by providing comprehensive country-specific and disease-specific estimates under three smoking prevalence scenarios using a dynamic forecasting framework.

With the use of the Institute for Health Metrics and Evaluation’s Future Health Scenarios platform, we aim to forecast all-cause and cause-specific YLLs for all countries from 2022 to 2050, as well as life expectancy gains, under three smoking prevalence scenarios. The reference scenario, which reflects a continuation of current trends in smoking prevalence, and the Tobacco Smoking Elimination as of 2023 (Elimination-2023) scenario, in which smoking prevalence is immediately reduced to zero, quantify the bounds of potential future health benefits from smoking elimination. The third scenario, Tobacco Smoking Elimination by 2050 (Elimination-2050), which includes a generational ban beginning in 2023 and a steady reduction of smoking prevalence to 5% among older cohorts by 2050, provides insight into what gains could be realised by countries considering policies to reach endgame targets. Together, these scenarios underscore the magnitude of health benefits, benefits that will continue to grow beyond 2050, which could be achieved if countries take action to end the global tobacco epidemic. This manuscript was produced as part of the GBD Collaborator Network and in accordance with the GBD Protocol.

Methods

Overview

We used the Future Health Scenarios platform to forecast YLLs under three smoking prevalence scenarios, for 204 countries and territories as well as 365 diseases and injuries by 5-year age group and sex from 2022 to 2050. In the following sections, we focus primarily on methods specific to this analysis of the effects of smoking prevalence reductions. The methods used to forecast population, fertility, and all-cause mortality have been reported elsewhere.[32–35] Methods and accompanying estimates for smoking-specific inputs, including smoking prevalence, continuous measures of intensity of exposure, and dose-response relative risks for 32 health outcomes have also been previously published.[1] In this analysis, we only report the direct effects from smoking tobacco, which do not include the health effects from second-hand smoke, smokeless tobacco use, or electronic nicotine delivery systems. This study adheres to the Guidelines for Accurate and Transparent Health Estimates Reporting statement (appendix 1 pp 16–17).[36]

Forecasting framework

We obtained estimates of independent drivers of health, including over 70 risk factor summary exposure values from the Global Burden of Diseases, Injuries, and Risk Factors Study (GBD), interventions such as vaccines and antiretroviral therapy coverage, and covariates such as Socio-demographic Index (a composite measure of income, education, and fertility under age 25 years) from GBD 2021, for every location, age, and sex, from 1990 to 2019. These independent variables were then forecasted to 2050, mostly using a generalised ensemble model that includes past annual rates of change and relationship with Socio-demographic Index to predict future trends (appendix 1 p 13).

Once we have a complete time series from 1990 to 2050 for each of the independent variables, we use them to forecast cause-specific mortality rates up to 2050. Future mortality is estimated using three components: underlying (risk-deleted) mortality, a risk factor scalar, and latent trends predicted with an autoregressive integrated moving average (0,1,0) model.[35] These cause-specific mortality estimates are aggregated to obtain all-cause mortality.[33] We used the methods published in Vollset and colleagues' study[33] to obtain life tables and population estimates to 2050. Briefly, age-specific and sex-specific future population was computed for each location based on future all-cause mortality, fertility, and net migration. Importantly, population and life expectancy were computed independently for each scenario, enabling us to capture the effects of differing mortality rates on population age structure and size. YLLs were then computed for each scenario using demographically aggregated mortality forecasts and the GBD reference life table.[33] Details on validation of our forecasting model can be found in previous studies.[32,33,35]

Smoking scenario definitions

We forecast cause-specific and all-cause mortality under three scenarios, which we refer to as the reference, Elimination-2023, and Elimination-2050 scenarios. The reference scenario assumes that past independent health driver trends and relationships between drivers and health outcomes persist into the future. To estimate an upper bound on the effect of reducing smoking prevalence, we constructed the Elimination-2023 scenario, under which past trends persist across all inputs except current smoking prevalence, which is reduced to zero from 2023 onwards. Finally, we constructed the Elimination-2050 scenario, under which past trends persist across all inputs except smoking prevalence, which is linearly reduced to 5% between 2023 and 2050. The Elimination-2050 scenario provides a benchmark that falls between the reference scenario and Elimination-2023 scenario.

For all scenarios, we use GBD 2021 estimates of distributions of cigarette-equivalents smoked per day and pack-years among current smokers, distributions of years since quitting among former smokers, and cause-specific relative risk estimates for both current and former smokers. We assumed the 2022 age-specific distributions of cigarette-equivalents smoked per day and pack-years among current smokers remained constant into the future. In the reference scenario, we similarly assumed the 2022 age-specific distributions of years since quitting among former smokers remained constant into the future. In the alternative scenarios, we shifted the 2022 years since quitting distributions for former smokers who quit in 2022 or earlier forward with every future year and created uniform distributions to model the years since quitting for former smokers who quit in 2023 or later. We then used these inputs, and scenario-specific prevalence forecasts for current smokers, former smokers, and never smokers, to compute population attributable fractions for smoking between 2020 and 2050, which in turn were used to compute smoking summary exposure values. The population attributable fraction calculation was adapted from the GBD study, with additional terms added to capture the burden among recent quitters (appendix 1 p 12).

See Online for appendix 1

Reference scenario forecast

The reference scenario is a probabilistic forecast that allows historical trends of drivers of health to continue into the future and holds the past relationship between drivers and health outcomes constant. To forecast smoking prevalence in this scenario, we first obtained current smoking and former smoking prevalence estimates for every location, sex, 5-year age group, and year from 1990 to 2019 from GBD 2021.[1] We then used an ensemble model to forecast current and former smoking prevalence from 2020 to 2050.[35] Briefly, the ensemble models consisted of six submodels that used annualised rates of change to forecast prevalence to 2050 based on past smoking trends. Each submodel had a recency-weighting parameter ranging from 0 to 2·5, in which larger values correspond to more weight given to the trend in recent years. Model performance was assessed using a 10-year holdout. The final forecast was a weighted average of these submodels with each weighted by the inverse of their root mean squared error.

Alternative smoking prevalence scenarios

The Elimination-2023 scenario was constructed with the reference scenario's current and former smoking prevalence values from 2020 to 2022, setting current smoking prevalence to 0% from 2023 onwards. We considered the population of current smokers in 2022 to be former smokers from 2023 onwards and tracked their years since quitting for every year from 2023 to 2050. For the population of existing former smokers that quit smoking between 1990 and 2022, we held the distribution of years since quitting constant and extended it into the future (ie, if for a given cohort the mean years since quitting was 10 in 2022, the mean years since quitting for that cohort would be 15 in 2027).

The Elimination-2050 scenario was constructed similarly. We created the scenario by setting smoking prevalence to zero for birth cohorts of ages 0–19 years in 2023. For older cohorts, we linearly reduced current smoking prevalence starting in 2023 to 5% by 2050. For older cohorts with current smoking prevalence rates below 5% in 2022, we held that prevalence rate constant to 2050. As in the Elimination-2023 scenario, we held the distribution of years since quitting constant and logically extended it into the future for the population of existing former smokers that quit smoking between 1990 and 2022. We used a uniform distribution of years since quitting for the population of former smokers that quit during or after 2023, since the proportion of people quitting between 2023 and 2050 was constant.

See Online for appendix 2

To account for the effects of different mortality rates between people who currently, formerly, and never smoked, we estimated the all-cause relative risks of mortality for each smoking status. First, we computed exposure-weighted relative risks by location, age, sex, and cause in 2022. We then aggregated these cause-specific relative risks across all causes to generate an all-cause relative risk of mortality. Finally, we computed the mortality rate among people who never smoked and used each of the mortality rates to adjust our prevalence estimates in every future year. As a result, the share of current and former smokers in the population decreased over time in each of the alternative scenarios.

Uncertainty estimation

Uncertainty intervals (UIs) were computed from distributions for each estimate generated by propagating 500 draws through the multistage computational pipeline. The 95% uncertainty interval of estimates is based on the 2·5th and 97·5th percentile of draws. We report results with the mean and UI for all three scenarios in the main text and tables, and only for the reference scenario in figures. We did all analyses using R (version 4.2.2) and Python (version 3.10.13).

Role of the funding source

The funders of the study had no role in study design, data collection, data analysis, data interpretation, or writing of the report.

Results

Smoking prevalence forecasts

The age-standardised prevalence of current smoking declined globally from 1990 to 2022, from 40·8% (95% UI 40·4–41·1) to 28·5% (27·9–29·1) among males aged 10 years and older, and from 9·94% (9·77–10·15) to 5·96% (5·76–6·21) among females aged 10 years and older (figure 1). We forecast that this decline will continue, albeit at a slower pace, with an age-standardised prevalence of 21·1% (20·6–21·6) among males and 4·18% (3·98–4·48) among females in 2050, a 25·9% (25·2–26·6) and 30·0% (26·1–32·1) decline relative to 2022, respectively. By 2050, the age-standardised prevalence among males is forecasted to range between 3·18% (2·95–3·47) in Brazil and 63·2% (60·6–65·6) in the Federated States of Micronesia, and among females between 0·50% (0·36–0·68) in Nigeria and 38·5% (35·2–41·8) in Serbia (appendix 2 pp 3–9). Despite a forecasted increase of the global population of 1·44 billion (95% UI 1·07–1·84) or 18·1% (95% UI 13·6–23·0) between 2022 and 2050, as well as population ageing, the number of current smokers is also forecast to decline. Globally, we forecast 1040 million (95% UI 980–1110) male smokers and 201 million (187–220) female smokers by 2050. The largest relative decline in the number of current smokers is forecasted to occur in Tropical Latin America and the largest increase in central sub-Saharan Africa for both sexes. Population growth is the largest factor responsible for increases in current smoking populations in most regions.

Global age-standardised prevalence of former smoking among those aged 20 years and older is forecast to stay relatively constant from 14·3% (95% UI 13·9–14·6) in 2022 to 14·2% (13·9–14·6) in 2050 among males and from 5·81% (5·60–6·05) to 5·50% (5·28–5·72) among

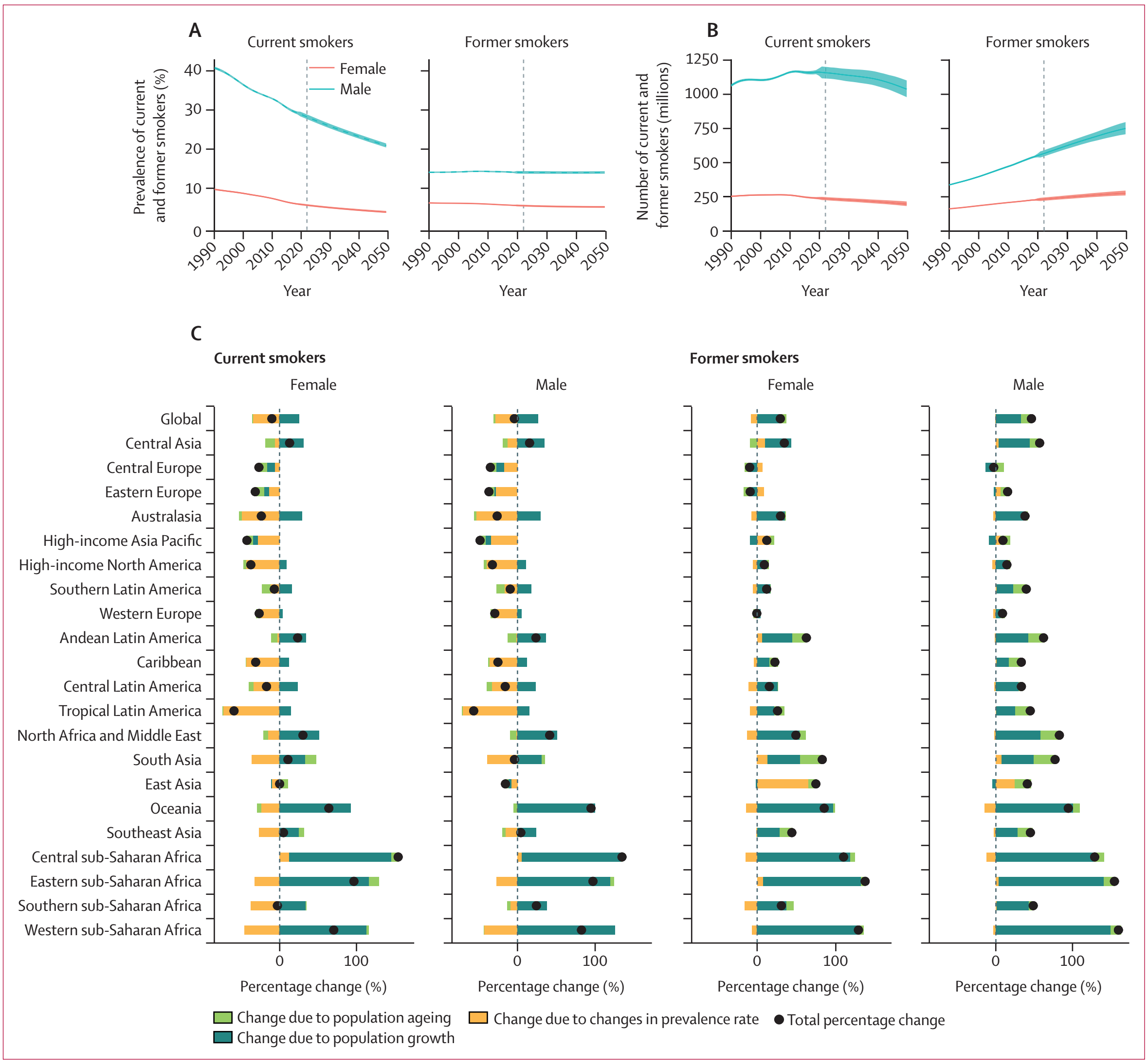


Figure 1: **Annual change in global smoking**

(A) Changes in current and former smoking prevalence over time, age standardised. (B) Number of current and former smokers over time for all ages. Estimates for 1990–2019 were obtained from GBD 2021 for (A) and (B). The solid lines in (A) and (B) indicate the mean estimate, whereas the shaded areas reflect the 95% uncertainty interval. (C) Decomposition of forecasted change in number of smokers from 2023 to 2050 due to population ageing, population growth, and changes in the prevalence rate among current and former smokers. The grey dashed vertical line in (A) and (B) indicates 2022 (the first forecast year). The black dots in (C) indicate the overall percentage change in the number of smokers from 2023 to 2050.

females. The forecasted age-standardised prevalence of former smoking among males in 2050 ranges between 3·80% (3·44–4·17) in Benin and 56·9% (54·1–59·1) in Tanzania, and among females between 0·47% (0·39–0·56) in Libya and 46·9% (42·9–51·5) in Tanzania. Due to a combination of population growth, ageing, and increases in the prevalence of former smoking, the number of former smokers is forecasted to increase by 28·5% (23·0–34·6) by 2050. Compared with 800 million (95% UI 771–835) former smokers in 2022, we forecast 1030 million (973–1090) former smokers in 2050. The number of former smokers is forecast to increase in most GBD regions, apart from central Europe among males and eastern Europe, central Europe, and western Europe among females. In these regions, declines in the population between 2022 and 2050 offset any increases in former smoking prevalence. Population growth and ageing are the largest factors responsible for increases in the former smoking population in the regions with an increasing number of former smokers.

YLLs under the reference scenario

YLLs represent the number of life-years lost due to premature death. Globally, there were 1020 million (95% UI 942–1090) YLLs among males and 757 million (705–810) among females in 2022 (figure 2). Under our reference scenario, we project that there will be 1040 million (932–1190) YLLs among males and

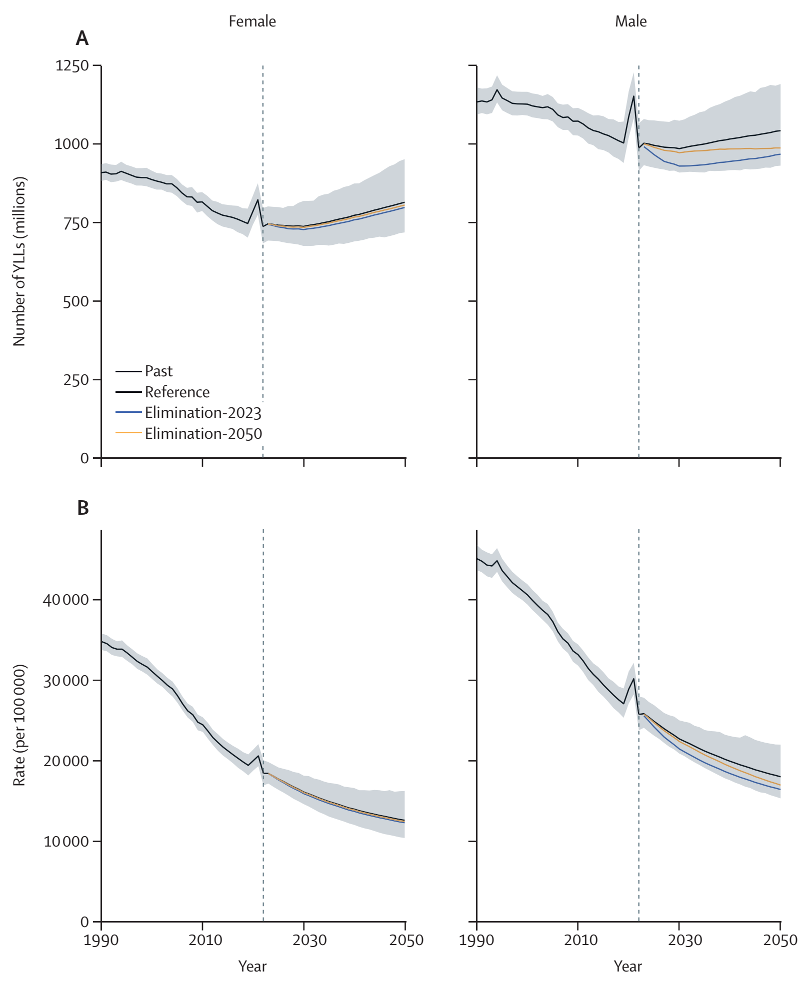


Figure 2: **Global YLLs by scenario, all causes**
The solid lines indicate the mean estimates of the number of all-age YLLs (A) and the rate of age-standardised YLLs (B). The shaded area reflects the 95% uncertainty interval for the past and reference scenario. Estimates for 1990–2021 were obtained from GBD 2021. The grey dashed vertical line indicates 2022 (the first forecast year). YLLs=years of life lost.

816 million (720–953) YLLs among females in 2050, for a cumulative total of 51·5 billion (47·3–56·9) future YLLs between 2022 and 2050. Although large, these global increases are a product of population growth and ageing. The global age-standardised rate of YLLs is forecast to decrease from 26 530·9 (24 623·2–28 614·0) per 100 000 among males in 2022 to 17 113·2 (14 553·3–20 949·3) per 100 000 in 2050, and from 18 919·3 (17 608·9–20 322·8) per 100 000 to 12 448·6 (10 282·1–16 034·6) per 100 000 among females. In our reference scenario non-communicable diseases comprise the majority of future YLLs, accounting for 68·1% (95% UI 64·9–70·8) of cumulative YLLs among females and 64·3% (61·8–66·3) among males (figure 3). Non-communicable diseases are also responsible for the largest age-standardised YLL rates, accounting for 11 273·6 (10 328·7–12 498·2) YLLs per 100 000 between 2022 and 2050 among males and 7760·4 (7007·3–8602·8) per 100 000 among females. Cardiovascular diseases and cancers are the leading causes of non-communicable diseases YLLs in this scenario, accounting for 12·3 billion (95% UI 10·8–14·1) and 9·05 billion (8·13–9·92) cumulative future YLLs, respectively.

YLLs under alternative scenarios

The difference between the number of YLLs under the reference scenario and Elimination-2023 scenario approximates the maximum number of future smoking-attributable YLLs that can be avoided. Our forecasts suggest that a maximum of 2040 million (95% UI 1900–2210) cumulative smoking-attributable YLLs are theoretically avoidable between 2022 and 2050, with 1700 million (1570–1850) YLLs avoidable among males and 341 million (318–369) YLLs avoidable among females globally. The GBD regions with the greatest number of avoidable YLLs are East Asia and South Asia, with 708 million (620–809) and 385 million (320–455) cumulative YLLs avoidable, respectively. The greatest decreases in the cumulative age-standardised rate of YLLs between these scenarios can be seen in Oceania and East Asia, with decreases of 1342·0 (95% UI 1057·9–1746·4) per 100 000, and 1076·2 (911·8–1274·7) per 100 000, respectively (figure 4). The largest gains could be accomplished in China, India, and Indonesia, with a potential 1·08 billion (95% UI 0·98–1·21) YLLs avoidable with smoking prevalence elimination as of 2023.

Under the Elimination-2050 scenario, gains in health burden as measured with YLLs are delayed relative to the Elimination-2023 scenario but are similar by 2050. Under this scenario, we project 735 million (95% UI 675–808) fewer cumulative YLLs among males and 141 million (131–154) fewer cumulative YLLs among females relative to the reference scenario. Of the 1700 million (1570–1850) avoidable YLLs among males and 341 million (318–369) avoidable YLLs among females if smoking prevalence was reduced to 0% globally in 2023, 43·2% (42·7–43·9) and 41·5% (40·9–42·1) are avoidable if smoking prevalence elimination is delayed until 2050. The GBD regions with the largest reductions in cumulative YLLs under the Elimination-2050 scenario relative to the reference are East Asia, with 336 million (298–379) cumulative avoidable YLLs, and South Asia, with 172 million (142–206) cumulative avoidable YLLs. The Elimination-2050 scenario forecasts an age-standardised rate of 20 038·4 (18 092·9–22 666·7) cumulative YLLs per 100 000 among males and 14 466·7 (12 785·2–16 594·3) per 100 000 among females, a reduction of 560·0 (505·7–629·0) per 100 000 and 95·7 (85·2–108·4) per 100 000 compared with the reference scenario. The countries that would have the largest number of YLLs avoided between 2022 and 2050 under the Elimination-2050 scenario are China, India, and Indonesia, with reductions of 328 million (289–371), 124 million (100–151), and 38 million (31·9–45·7), respectively.

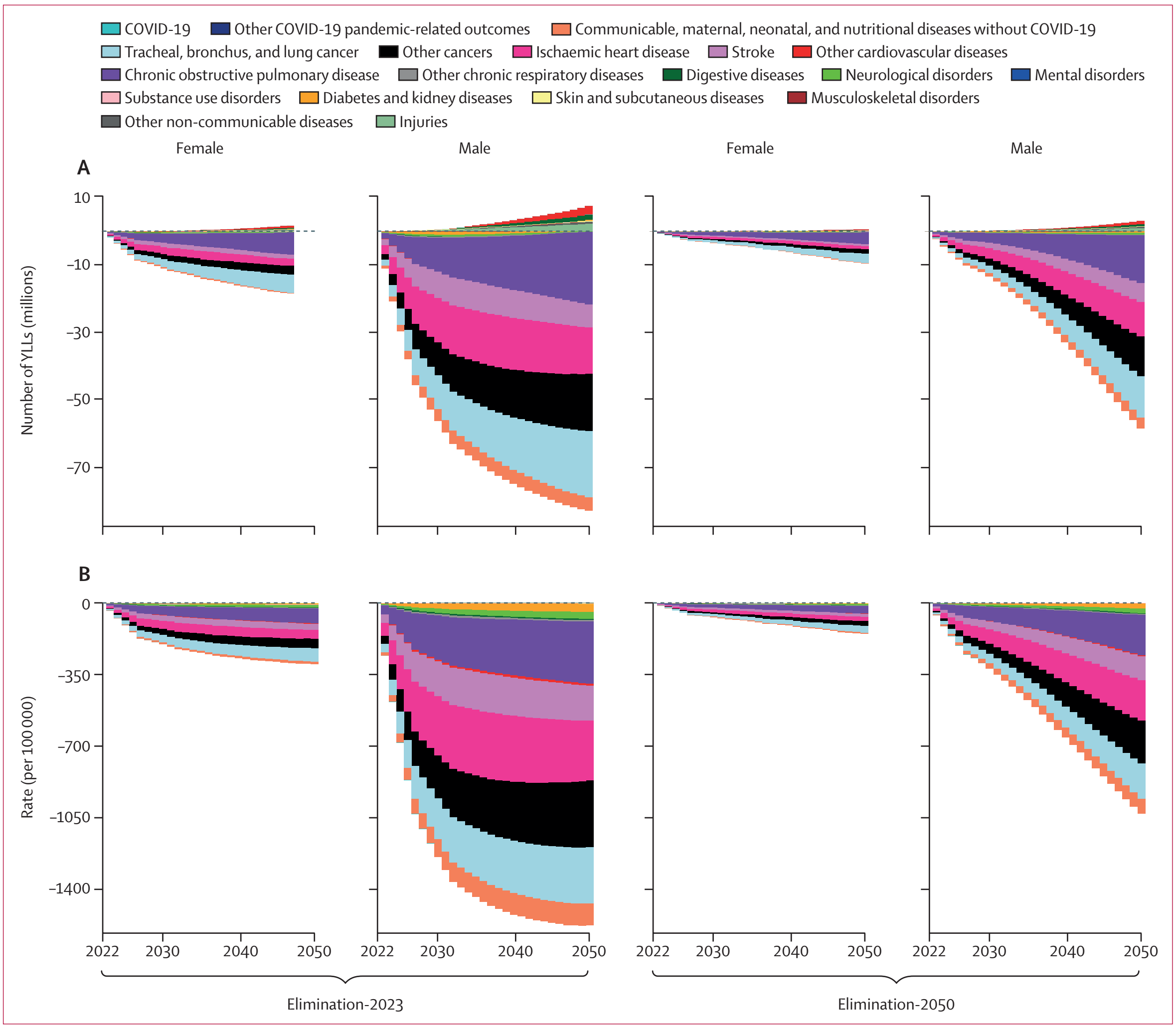
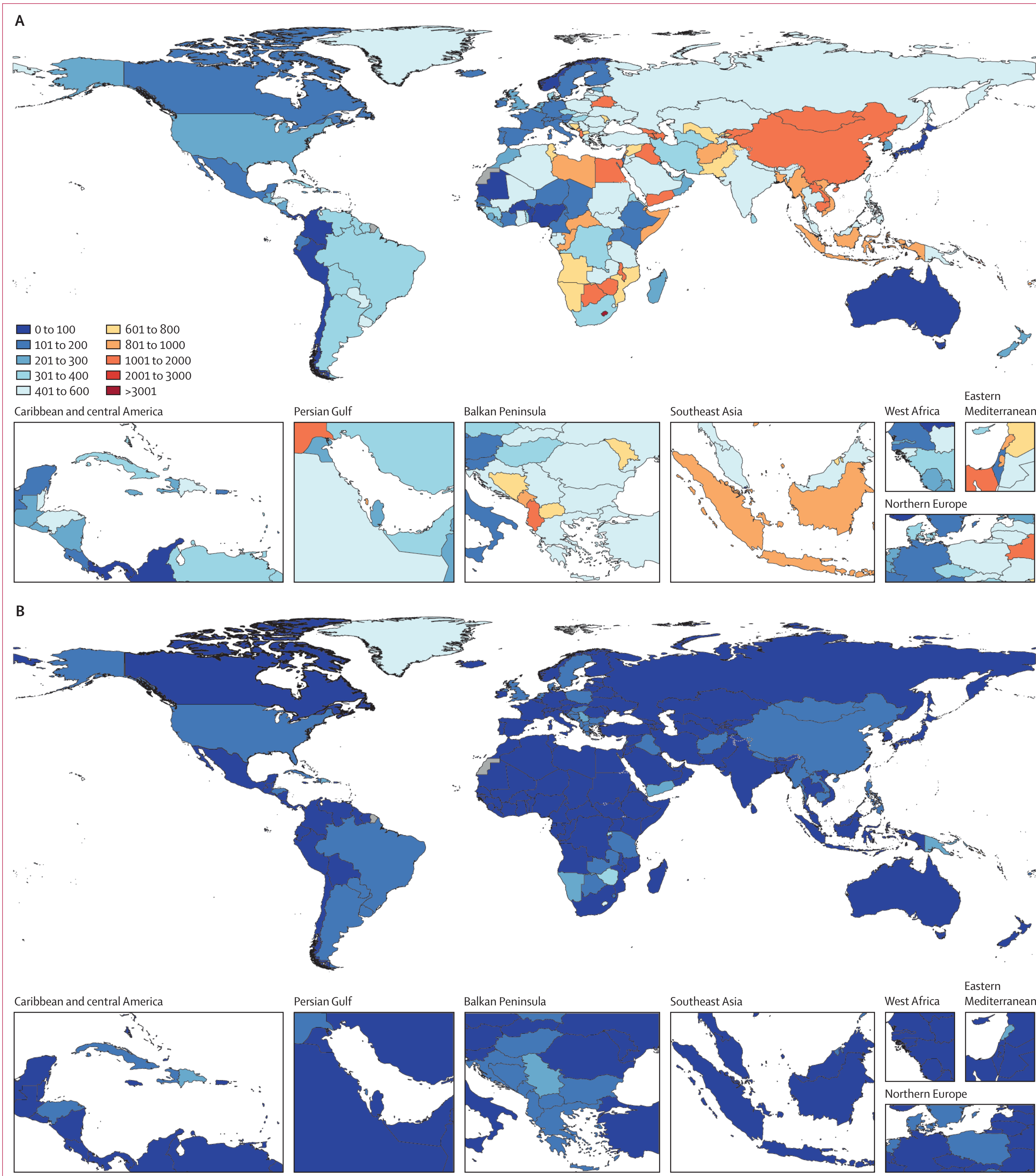


Figure 3: **Global YLLs by GBD Level 2 causes of death under the reference scenario, Elimination-2050 scenario, and Elimination-2023 scenario**
(A) Difference in number of YLLs compared with the reference scenario. (B) Difference in rate of age-standardised YLLs compared with the reference scenario. Negative net differences in (A) and (B) indicate causes from which YLLs would be avoided under each custom scenario, whereas net positive differences indicate causes from which additional YLLs would occur. YLLs=years of life lost.

Cancers, ischaemic heart disease, and chronic obstructive pulmonary disease (COPD) account for 85·2% (95% UI 81·4–87·2) of avoidable YLLs. Cancers account for 692 million (595–782) avoidable YLLs among males and 140 million (121–159) among females, with lung cancer responsible for 51·8% (47·9–55·1) of avoidable cancer YLLs among males and 62·6% (59·3–65·7) of avoidable cancer YLLs among females. COPD and ischaemic heart disease account for 482 million (413–552) and 426 million (332–549) of all avoidable YLLs, respectively. Even if smoking is globally eliminated, premature death will still occur due to other drivers, such as air pollution or obesity. Under the Elimination-2050 scenario, 876 million (810–958) YLLs could be avoided relative to the reference scenario. COPD, ischaemic heart disease, and lung cancer are the leading causes of avoidable YLLs under this scenario, accounting for 220 million (190–253), 175 million (130–236), and 178 million (142–213) YLLs, respectively. However, unlike the Elimination-2023 scenario, under the Elimination-2050 scenario, the majority of avoidable YLLs occur after 2040 (59·4% [58·9–60·1], relative to 44·0% [43·4–44·8] under the Elimination-2023 scenario). Time series plots of the YLLs forecast under each of these scenarios for ischaemic heart disease, lung cancer, and COPD are available in appendix 2 (pp 27–30).

Life expectancy at birth

Global life expectancy at birth has increased between 1990 and 2022 by 7·95 years (95% UI 6·81–9·05) among males (63·1 years [62·4–63·7] to 71·1 years [70·1–72·0]) and 8·1 years (7·2–9·0) among females (68·1 years [67·6–68·6] to 76·2 years [75·5–77·0]; figure 5). Under the reference scenario, we forecast that the life expectancy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0 to 100
101 to 200
201 to 300
301 to 400
401 to 600
601 to 800
801 to 1000
1001 to 2000
2001 to 3000
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Caribbean and central America
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Southeast Asia
West Africa
Eastern Mediterranean
Northern Europe

at birth would continue to increase, climbing to 76·1 years (73·6–78·0) among males and 80·6 years (78·1–82·6) among females in 2050. If smoking were to be eliminated in 2023, the life expectancy would increase to 77·6 years (75·1–79·6) among males and 81·0 years (78·5– 83·1) among females in 2050, globally. This corresponds to a 31·0% (23·1–52·1) among males and 10·4% (6·8–22·2) among females larger gain in life expectancy under the Elimination-2023 scenario compared with the reference scenario. The GBD regions with the largest gains in life expectancy among males relative to the reference under the Elimination-2023 scenario would be East Asia, Eastern Europe, and Central Asia, with 2·6 (2·3–2·8), 2·0 (1·9–2·0), and 1·9 (1·9–2·0) additional years, respectively. Among females, the GBD regions with the largest gains in life expectancy by 2050 possible with elimination of smoking prevalence in 2023 are high-income North America, East Asia, and Oceania, with 0·9 (0·8–0·9), 0·7 (0·7–0·8), and 0·7 (0·6–0·9) additional years, respectively. Under the Elimination-2050 scenario, life expectancy at birth would increase by a further 1·0 years (0·9–1·0) among males and 0·2 years (0·2–0·2) among females globally, relative to the reference scenario. Similar to the Elimination-2023 scenario, the GBD regions with the largest gains in life expectancy among males under the Elimination-2050 scenario would be East Asia, Central Asia, and Southeast Asia, with 1·8 (1·6–2·0), 1·3 (1·2–1·4), and 1·2 (1·1–1·3) additional years of life gained. Among females, the GBD regions with the largest gains in life expectancy are East Asia, high-income North America, and Oceania, with 0·5 (0·4–0·6), 0·3 (0·3–0·4), and 0·3 (0·3–0·4) years gained.

Discussion

In this Article, we present forecasts of smoking prevalence and resulting YLLs and life expectancy to 2050 for a reference scenario and two alternative scenarios. We forecast that 2040 million (95% UI 1900–2210) years of life will be lost to smoking between 2022 and 2050, of which 1·70 million (1·85–1·57), or 83·3% (95% UI 82·3–84·2) are among males. With our reference scenario, we forecast an additional gain in life expectancy of 4·8 years (95% UI 2·4–6·4) between 2022 and 2050. Life expectancy increased globally by an additional 1·5 years (1·5–1·6) among males and 0·4 years (0·4–0·4) among females between 2022 and 2050 in our Elimination-2023 scenario, and 1·0 years (0·9–1·0) and 0·2 years (0·2–0·2) in our Elimination-2050 scenario. The additional years of life expectancy forecast in the Elimination-2050 scenario represent an increase of 19·6% (95% UI 14·7–32·9) among males and 5·33% (3·62–11·09) among females, compared with our reference scenario. Our analysis shows that large population health gains can be achieved by accelerating progress towards smoking elimination.

This level of benefit is rare from a single, feasible intervention. In comparison, increased health-care spending per capita by 10% over a 20-year period has been estimated to have improved life expectancy in Organisation for Economic Co-operation and Development countries by 3·5 months.[37] Increases of 10% in income per capita and primary educational attainment were estimated to improve life expectancy by 2·2 months and 3·2 months, respectively.[37] Accelerated progress with regard to a single behavioural risk factor would result in life expectancy gains that are greater than these advancements. Importantly, these gains represent an average across the entire population, including people who have never smoked, and are therefore underestimates of the gains expected among smokers.

This analysis represents a substantial advancement of our ability to forecast smoking-attributable burden. To more accurately translate the effects of smoking prevalence to health burden, we built a novel framework for forecasting the health burden of tobacco use, based on the framework established in GBD. This framework allowed us to directly translate prevalence changes to population attributable fractions and summary exposure values and leverage the Future Health Scenarios platform to translate these measures into the health effects of these scenarios for all countries and causes measured by GBD. Furthermore, it allows us to quantify the maximum future health gains possible through smoking

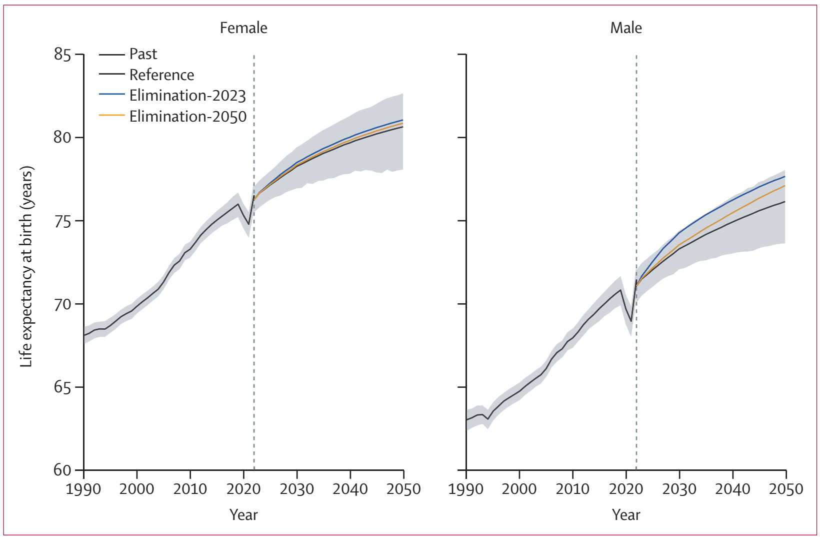

Figure 5: **Global life expectancy at birth by sex and scenario**
The solid lines indicate the mean estimates of life expectancy at birth. The shaded area reflects the 95% uncertainty interval for the past and reference scenario. The grey dashed vertical line indicates 2022 (the first forecast year). Estimates for 1990 to 2021 were obtained from GBD 2021.

Figure 4: **Difference in cumulative age-standardised rate of YLLs compared with the reference scenario 2022 to 2050 (per 100 000)**
(A) The difference in the cumulative age-standardised rate of YLLs between the reference scenario and the Elimination-2050 scenario among males. (B) The difference between the reference scenario and the Elimination-2050 scenario among females. YLLs=years of life lost.

elimination, as well as the population dynamics that would result through such elimination. We are able to capture excess future risk among former smokers due to past smoking exposure. Our analysis shows that smoking intervention would result in longer lives lived by current and former smokers. This analysis also allows us to capture the important effect of competing risks. Rather than dying prematurely from ischaemic heart disease or lung cancer, individuals would gain years of life. However, they inevitably would die later, either from causes attributable to other risk factors, or from illnesses related to older age. The fluid, time-varying nature of the potential health gains were important in our decision to use YLLs rather than deaths as our measure of interest. We present cumulative YLLs rather than annual YLLs throughout this analysis for similar reasons. The question is not whether people will die, either due to smoking or another driving factor, but rather how much longer their lives could be in the absence of smoking. Further work is needed to understand these dynamic relationships.

Our analysis likely underestimates the total benefits of smoking elimination in two ways. First, since 62·4% (95% UI 61·1–63·6) of smoking-attributable burden in 2021 was among individuals aged 60 years and older, and our simulation's first smoke-free generation will be at most aged 57–61 years by 2050, the majority of health gains from the smoke-free generation component of our smoking elimination scenarios will not be observed until after 2050. As a result, health gains from smoking elimination will continue to grow well beyond 2050. Second, the full health gains possible under the alternative scenarios will not begin to be realised until enough time has passed that all residual risk among former smokers has dissipated. Under the Elimination-2050 scenario, this would not occur until approximately 2080, 30 years after the last smokers quit. These factors highlight the importance of using a package of policies that include efforts directed at helping current smokers reduce their consumption and quit. In future studies, we plan to extend the forecasts to at least 2100, so that we can follow the relevant cohorts to old age and thus capture the full effect of the smoking elimination scenarios.

Our analysis has several limitations. First, we analysed the direct effects of reductions in smoking prevalence on disease burden. Although we did not quantify them, we anticipate additional health benefits under these scenarios in terms of reductions in second-hand smoke exposure. Second, while our analysis considers additional years of life possible with smoking prevalence reduction, we did not quantify the benefits to quality of life lived free of disease. Further health benefits would likely occur under these scenarios in terms of more years lived without disability. Third, our forecast model assumes that the age-specific smoking initiation rates, distributions of cigarette-equivalents smoked per day by current smokers, pack-years among current smokers, and years since quitting among former smokers would remain constant into the future. This assumption is consistent with observed data that smoking intensity is largely stable over time, even as prevalence varies. Fourth, our alternative scenarios only act to reduce smoking prevalence, and do not include additional benefits that could be achieved by reducing smoking intensity. Fifth, we do not model substitution with electronic nicotine delivery systems and assume that recent quitters take on the risk profile of former tobacco smokers, not current users of electronic nicotine delivery systems. Sixth, the reference scenario that is used as the benchmark against which potential health gains are measured assumes that past trends in drivers of health persist. As a result of this assumption, our reference forecasts reflect historical progress in the reduction of many causes of health burden, such as communicable, maternal, neonatal, and nutritional diseases, that resulted from substantial investment. For the future forecast under this scenario to be realised, this investment will need to continue. Similarly, each of our scenarios assume that the relationship between drivers of health, such as smoking, and health outcomes will continue into the future. If improvements in lung cancer detection or treatment accelerate, the need for smoking elimination would be reduced. Seventh, the past data that we forecast comes from GBD, which carries its own limitations. For instance, data on tobacco use is self-reported, which is subject to under-reporting and social desirability bias, particularly in demographics among which smoking is not socially accepted. Finally, we do not quantify the health gains possible under a worse scenario in which smoking exposure intensifies relative to past trends, or other scenarios in which other risk factor exposure does not continue as it has in the past. Despite these limitations, our analysis represents an important quantification of the health gains possible under various smoking prevalence scenarios.

This study is an advancement of our ability to forecast smoking-attributable burden for every country and cause represented in the GBD. Although global smoking prevalence will continue to decrease in the reference scenario, substantial burden will still accumulate in the future due to smoking. Smoking elimination, even by 2050, would result in gains in life expectancy at birth at a rate not possible by many other interventions. Further research, with forecasts to 2100 encompassing avoidable second-hand smoke burden, is needed to generate a more complete understanding of the gains possible with smoking elimination. Accelerated adoption of anti-tobacco policies in all countries is needed, and equally, existing policies must be maintained to build upon the gains won since the adoption of the Framework Convention on Tobacco Control. Timely action is crucial to ensure the maximum amount of health burden is avoided in the coming decades.

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See **Online** for appendix 3

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Please see appendix 3 for more detailed information about individual author contributions to the research, divided into the following categories: managing the overall research enterprise; writing the first draft of the manuscript; primary responsibility for applying analytical methods to produce estimates; primary responsibility for seeking, cataloguing, extracting, or cleaning data; designing or coding figures and tables; providing data or critical feedback on data sources; developing methods or computational machinery; providing critical feedback on methods or results; drafting the manuscript or revising it critically for important intellectual content; and managing the estimation or publications process. The corresponding author had full access to all the data in the study and had final responsibility for the decision to submit the manuscript for publication. The lead and senior authors and members of the core research team for this topic area had full access to the underlying data used to generate estimates presented in this Article. All other authors had access to and reviewed estimates as part of the research evaluation process, which includes additional stages of formal review.

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Data sharing

To download the GBD data used in these analyses, please visit the Global Health Data Exchange GBD 2021 website (https://ghdx.healthdata.org/gbd-2021/sources). To download forecasted estimates used in these analyses, please visit the GBD tobacco forecasting visualisation tool (https://vizhub.healthdata.org/tobacco-forecasting/).

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