

Air quality targets and projected health and economic benefits in China: a modelling study

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Submitted to: JMIR Public Health and Surveillance
on: September 25, 2025

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Abstract

Background: Air pollution continues to pose a significant health and economic burden in China, with PM_{2.5} concentrations remaining six times above WHO guidelines despite recent progress.

Objective: This modelling study evaluates the projected health and economic benefits of reducing national PM_{2.5} levels.

Methods: Using 2020 ground-level PM_{2.5} data as a baseline, we projected cause-specific mortality and morbidity outcomes for 337 prefecture-level cities in China from 2020 to 2030 under four policy scenarios: (1) Healthy China 2030 (10% reduction by 2025; 25 μ g/m³ by 2030), and the WHO targets of (2) 15 μ g/m³, (3) 10 μ g/m³, and (4) 5 μ g/m³ by 2030. Mortality from non-communicable diseases (NCD), lower respiratory infections (LRI), stroke, ischaemic heart disease (IHD), lung cancer (LC), and chronic obstructive pulmonary disease (COPD) was estimated using the Global Exposure Mortality Model (GEMM). Hospitalisations were modelled using log-linear functions based on national epidemiological data.

Results: We estimated an average annual reduction of 179,274 in PM_{2.5}-attributable premature deaths across 337 cities. This included 54,726 deaths from IHD, 63,680 from stroke, 15,437 from COPD, 4,968 from LRI, and 24,485 from LC. Annual average reductions in hospitalisations were estimated at 47,967 cases, including 21,423 cases for cardiovascular disease (CVD) and 26,544 cases for respiratory diseases. Subsequently, economic benefits from reductions in mortality and morbidity across 337 cities amounted to \$87.5 billion USD. Achieving the 15, 10, and 5 μ g/m³ targets is projected to increase annual premature death reductions to 376,863, 489,528, and 626,157, respectively, with corresponding hospitalisation decreases of 93,371, 116,217, and 139,219 cases per year. These reductions would yield increased annual economic benefits of \$185.7 billion, \$240.7 billion, and \$306.5 billion USD, respectively.

Conclusions: Our findings suggest that while the Healthy China 2030 Plan offered substantial health gains, achieving stricter WHO air quality targets could yield 2–3 times greater benefits. These findings will support the future development of stricter evidence-based national air quality standards.

(JMIR Preprints 25/09/2025:84809)

DOI: <https://doi.org/10.2196/preprints.84809>

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Original Manuscript

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Abstract**Background**

Air pollution continues to pose a significant health and economic burden in China, with PM2.5 concentrations remaining six times above WHO guidelines despite recent progress.

Objective

This modelling study evaluates the projected health and economic benefits of reducing national PM2.5 levels.

Methods

Using 2020 ground-level PM2.5 data as a baseline, we projected cause-specific mortality and morbidity outcomes for 337 prefecture-level cities in China from 2020 to 2030 under four policy scenarios: (1) Healthy China 2030 (10% reduction by 2025; 25 $\mu\text{g}/\text{m}^3$ by 2030), and the WHO targets of (2) 15 $\mu\text{g}/\text{m}^3$, (3) 10 $\mu\text{g}/\text{m}^3$, and (4) 5 $\mu\text{g}/\text{m}^3$ by 2030. Mortality from non-communicable diseases (NCD), lower respiratory infections (LRI), stroke, ischaemic heart disease (IHD), lung cancer (LC), and chronic obstructive pulmonary disease (COPD) was estimated using the Global Exposure Mortality Model (GEMM). Hospitalisations were modelled using log-linear functions based on national epidemiological data.

Results

We estimated an average annual reduction of 179,274 in PM2.5-attributable premature deaths across 337 cities. This included 54,726 deaths from IHD, 63,680 from stroke, 15,437 from COPD, 4,968 from LRI, and 24,485 from LC. Annual average reductions in hospitalisations were estimated at 47,967 cases, including 21,423 cases for cardiovascular disease (CVD) and 26,544 cases for respiratory diseases. Subsequently, economic benefits from reductions in mortality and morbidity across 337 cities amounted to \$87.5 billion USD. Achieving the 15, 10, and 5 $\mu\text{g}/\text{m}^3$ targets is projected to increase annual premature death reductions to 376,863, 489,528, and 626,157, respectively, with corresponding hospitalisation decreases of 93,371, 116,217, and 139,219 cases per year. These reductions would yield increased annual economic benefits of \$185.7 billion, \$240.7 billion, and \$306.5 billion USD, respectively.

Conclusion

Our findings suggest that while the Healthy China 2030 Plan offered substantial health gains, achieving stricter WHO air quality targets could yield 2–3 times greater benefits. These findings will support the future development of stricter evidence-based national air quality standards.

Keywords

China, health impact modelling, particulate matter, economic benefits, air pollution

1. Introduction

Ambient air pollution remains a critical public health issue in China, contributing to an estimated 1.67 million premature deaths nationwide in 2020 [1]. Exposure to particulate matter (PM) is the nation's fourth leading risk factor for overall mortality and disability-adjusted life years (DALYs), with a growing body of epidemiological research linking it to increased mortality, higher hospitalization rates, and reduced life expectancy [2-6]. Overall, this contributes substantially to both the health and economic burden, with several studies estimating associated annual economic losses ranging from 0.92% to 3.6% of national gross domestic product (GDP) within the past decade [1,7,8]. Recognising the severity of this challenge, the Chinese government introduced the Air Pollution Prevention and Control Action Plan in 2013, setting ambitious targets to reduce pollution levels [9]. The plan aimed to lower particulate matter concentrations in prefecture-level cities and above by at least 10% from 2012 levels by 2017. Consequently, the annual average PM_{2.5} concentration in 74 major cities declined by 33.3%, from 72.2 µg/m³ in 2013 to 47.0 µg/m³ in 2017 [10]. This improvement has resulted in substantial health benefits, including an estimated reduction of 47,240 deaths and the prevention of 710,020 years of life lost (YLL) [10].

In 2021, the World Health Organization (WHO) updated its air quality guidelines, lowering the recommended annual average PM_{2.5} concentration to 5 µg/m³ [11]. This revision reflects a growing body of epidemiological evidence demonstrating that both short- and long-term exposure at low threshold levels to PM can still result in adverse health effects [12-14]. Despite significant improvements in air quality, PM_{2.5} levels in 2020 remained seven times higher than the updated recommended limit. As part of its commitment to building a "Beautiful China", the government introduced a new set of air quality standards under the latest Clean Air Action Plan, aiming to reduce the annual mean PM_{2.5} concentration by 10% between 2020 and 2025, and achieving the interim target of 25 µg/m³ by 2030 [15]. This initiative underscores China's ongoing efforts to mitigate the health and economic burdens associated with air pollution.

Currently, much is known about the national health and economic disease burden associated with PM_{2.5} exposure. For example, Maji et al. estimated the disease burden associated with PM_{2.5} across 338 cities, reporting that PM_{2.5}-attributable mortality reached 0.964 million in 2016, accounting for 9.98 percent of total reported deaths in China that year [1]. Other national-level estimates since 2010 have ranged from 1.02 million to 2.20 million deaths [16-20]. Additionally, several studies have also retrospectively examined the benefits of previous air quality guidelines or policies, either nationally or at a regional level. Xu et al. assessed the health and economic impacts of clean air policies in the Beijing-Tianjin-Hebei region, estimating a reduction of 24,000 premature deaths and associated economic benefits of \$60 billion USD [21]. Zhang et al. compared the benefits of the previous five-year Clean Air Action Plan with its implementation costs, reporting that the public health benefits of air quality improvements were 1.5 times greater than the mitigation costs [22]. However, understanding of the potential benefits of future air quality improvements, particularly those projected under the latest clean air policies, remains limited. Given the significant gap between current national air quality standards and WHO recommendations, evaluating the health and economic impacts of national air policies is essential for supporting evidence-based decision-making as China advances toward its Healthy China 2030 goals. To bridge this dearth of evidence, we modelled the attributable health and economic outcomes associated with achieving the latest national regulations from 2021 to 2030, as well as the additional benefits associated with reaching the more stringent WHO targets of 15, 10, and 5 µg/m³ over the same period from a health system perspective.

2. Methods

2.1 Policy scenarios and model period

We projected cause-specific mortality and morbidity outcomes for 337 prefectural-level cities in China from 2020 to 2030 under several air quality improvement scenarios. These include: (1) a 10% reduction in PM_{2.5} by 2025, targeting 25 µg/m³ by 2030, representing the policy scenario under the current clean air action plan; (2-3) a stepwise reduction to WHO interim targets, with annual PM_{2.5}

concentration levels reaching 15 $\mu\text{g}/\text{m}^3$ (Interim Target III), and 10 $\mu\text{g}/\text{m}^3$ (Interim Target IV) by 2030, respectively; and (4) achieving the WHO's recommended air quality guideline of 5 $\mu\text{g}/\text{m}^3$ by 2030. To account for population changes, age- and sex-specific baseline population data were projected for the modelled period under shared socioeconomic pathways for each of the air quality scenarios. Supplementary Table 1 presents the matrix summarising the air quality scenarios and population projections considered in this analysis.

2.2 Assessment of Human Health Impacts

We employed the widely used health impact function to model mortality and morbidity outcomes under the policy scenarios [23]. Specifically, the health impact function is given as:

$$\Delta y = \frac{x_0 * (RR - 1)}{RR} * Pop$$

where the health endpoint attributable to PM_{2.5} (Δy) is a function of the baseline incidence rate x_0 , the population attributable risk [(RR-1)/RR], and the population at risk (Pop). Mortality outcomes included the combined category of non-communicable diseases and lower respiratory infections (NCD+LRI), alongside five specific causes: stroke, ischemic heart disease (IHD), chronic obstructive pulmonary disease (COPD), lung cancer (LC), and lower respiratory infections (LRI). Morbidity outcomes assessed included hospital admissions related to cardiovascular (CVD) and respiratory conditions.

2.2.1 Mortality attributable to PM_{2.5} exposure

Mortality attributable to PM_{2.5} exposure under baseline and policy scenarios was estimated using the Global Exposure Mortality Model (GEMM), which provides age- and cause-specific hazard ratios for non-accidental mortality [24]. The Global Exposure Mortality Model (GEMM) is a multivariate random effects model that synthesizes evidence from 41 cohort studies globally to characterize the exposure-response relationship between ambient air pollution and non-accidental mortality and has been widely applied in health assessment studies of ambient air pollution internationally. Details of the model have been described elsewhere [24]. In brief, the GEMM characterises the exposure-response relationship as:

$$Gemm(z) = \exp \left(\frac{\theta \log \left(\frac{z}{\alpha} + 1 \right)}{1 + \exp \left(\frac{-z - \mu}{v} \right)} \right), \text{ where } z = \max(0, PM_{2.5} - 2.4)$$

where θ , α , μ , and v are parameters that define the shape of the relationship. We selected the GEMM as it provides the most up-to-date risk estimates for the relationship between ambient air pollution and mortality globally, incorporating risk information from high-pollution regions such as China. Additionally, the GEMM has demonstrated that mortality estimates attributable to particulate matter exposure may be several times higher compared to those derived from other previously used risk functions, which integrate exposure data from multiple sources, including both indoor and outdoor environments [24,25]. Supplementary table 2 provides details on the parameters of the GEMM.

2.2.2 Morbidity attributable to PM_{2.5} exposure

Cardiovascular and respiratory disease-specific hospital admissions attributable to PM_{2.5} exposure were estimated using log-linear models. Log-linear models have previously been used in the literature for the assessment of PM_{2.5}-related mortality and morbidity outcomes, particularly in high pollution regions such as China [1,26,27]. Specifically, the function is defined as:

$$RR(z) = \exp [\beta (z - z_0)]$$

Where β denotes the exposure-response coefficient, representing the change in incidence of the disease-specific outcome for each $\mu\text{g}/\text{m}^3$ increase in PM_{2.5} concentration, and z_0 is the threshold concentration. Consistent with recent epidemiological evidence demonstrating that PM_{2.5} exposure can have adverse health effects even at low concentrations, no threshold concentration was applied in

this analysis. Supplementary Table 3 provides an overview of the disease-specific mortality and morbidity outcomes assessed in this study, along with the corresponding exposure-response coefficients derived from national and international studies.

2.3 Estimating health and economic benefits

To estimate the economic impact from reductions in mortality and morbidity, we employed the value-of-statistical life (VSL) and cost-of-illness (COI) methods. Briefly, VSL represents the monetary value assigned to reducing the risk of mortality, offering a quantitative basis for informing government decisions on environmental and health policies [28]. The estimate is derived from survey-based assessments of individual's stated willingness to pay (WTP) for incremental reductions in mortality risk [29]. To ensure the estimates adequately reflected the risk and income specific to the Chinese context, we employed VSL values derived from a recent national-level study, estimated at \$689,659 USD [30]. To quantify morbidity benefits, we employed the COI method, which estimates the economic burden of disease [31]. Reductions in direct costs were estimated by multiplying the average hospitalization costs for cardiovascular and respiratory diseases by the projected decrease in hospital admissions under improved air quality scenarios. Baseline figures in 2020 were projected using time series regression, assuming that historical trends continued over the modelled period. We employed a 5% discount rate, consistent with China's economic evaluation guidelines [32].

2.3 Data source

Air quality monitoring data between January 1st and December 31st 2020 were collected from the National Environmental Monitoring Centre (<https://air.cnemc.cn:18007/>), which contains hourly PM_{2.5} concentrations collected from 1,497 monitoring sites in 338 Chinese cities at the prefectural level and above. For baseline age- and cause-specific mortality in 2020, national-level estimates disaggregated by region (western, central, and eastern China) were utilized in the absence of city-level data. These estimates were derived from the CDC's mortality surveillance system, a national death registry covering over 605 counties and districts (21.1% of all counties and districts in China) [33]. Baseline mortalities under the business-as-usual scenario were projected for the modelled period using estimates from an existing study, which assessed risk factor exposures and associated NCD mortality trends based on Global Burden of Disease data through 2030 [34]. For morbidity, baseline cardiovascular and respiratory hospitalization incidences and hospitalisation costs were sourced from national and provincial statistical yearbooks and projected forward based on historical trends [35]. Moreover, age- and sex-specific baseline demographic data for 337 cities in 2020 were also extracted from statistical yearbooks. Supplementary Table 4 presents the primary data sources used in our health prediction model, while Supplementary Table 5 summarises the key assumptions underlying our analyses.

3. Results

3.1 PM_{2.5} concentrations

Figure 1 illustrates the spatial distribution of PM_{2.5} levels across 337 cities. In 2020, PM_{2.5} concentrations across 337 cities ranged from 7 µg/m³ to 63 µg/m³, with a national annual average of 32.6 µg/m³, falling below the 35 µg/m³ national guidelines but exceeding the WHO-recommended target of 5 µg/m³ by more than sixfold. Higher concentrations were observed in the east compared to the west, with densely populated regions such as the Beijing-Tianjin-Hebei (BTH), Fenwei Plain (FP), and Yangtze Delta (YRD) reporting PM_{2.5} levels of 50.7 µg/m³, 47.8 µg/m³, and 36.7 µg/m³, respectively. Overall, our analysis accounted for nearly 70% of the total population of China in 2020.

3.2 Mortality

Figure 2 presents the estimated burden of premature mortality attributable to PM_{2.5} exposure across the modelled scenarios, based on the SSP2 population trajectory. Between 2021 and 2025, under the baseline scenario in which PM_{2.5} concentrations remained at 2020 levels, exposure was projected to contribute to 9.04 million (95% CI: 7.70-10.67 million) attributable deaths. Under the policy scenario, where concentrations were reduced by 10% from 2020 to 2025, this estimate declined to 8.63 million (95% CI: 7.42-10.30 million), corresponding to an additional 0.41 million premature

deaths averted under the 14th Five-Year Clean Air Plan. Over the full modelled period from 2021 to 2030, the total number of PM_{2.5}-attributable deaths was estimated at 17.76 million (95% CI:14.21-20.95 million) under the baseline scenario, while the policy scenario resulted in a lower estimate of 15.96 million (95% CI:12.85-19.15 million). If PM_{2.5} concentrations were further reduced to the WHO's more stringent targets, the estimated number of attributable deaths would decline correspondingly to 13.99 million (95% CI:11.25-15.25 million) under a 15 µg/m³ scenario, 12.86 million (95% CI:10.85-14.85 million) under a 10 µg/m³ scenario, and 11.49 million (95% CI:8.96-13.45 million) under a 5 µg/m³ scenario, respectively.

The spatial distribution of the annual average reduction in total premature deaths across provinces for each modelled scenario is shown in **Figure 3**. The greatest reductions in mortality were observed in the eastern and south-eastern regions, particularly in highly populated and heavily polluted areas such as the BTH, FP, and YDR regions, compared to the west. Under the policy scenario, the estimated reduction in average annual premature deaths over the 10-year period was 13,879 for the BTH region, 7,009 for the FP region, and 6,895 for the YDR region. Similar spatial patterns of avoided premature deaths were observed under the WHO scenarios. In the most polluted regions (BTH, FP, and YDR), the estimated annual average benefits of reaching 15 µg/m³ corresponded to 237,580, 165,989, and 142,120 deaths averted, respectively. For the 10 µg/m³ scenario, these estimates increased to 283,878, 217,406, and 171,727, while for the 5 µg/m³ scenario, the reductions in premature deaths reached 338,916, 279,313, and 206,993, respectively.

Figure 4 presents the annual average reduction in cause-specific premature deaths attributable to improved air quality for each modelled scenario under the SSP2 pathway. Under the policy scenario, a 10% reduction in PM_{2.5} concentrations by 2025, followed by a further reduction to 25 µg/m³ by 2030, is projected to result in an average annual reduction of 179,274 premature deaths. This includes 54,726 deaths from IHD, 63,680 from stroke, 15,437 from COPD, 4,968 from LRI, and 24,485 from LC. If PM_{2.5} concentrations were further reduced to the WHO's interim and final targets (15, 10 and 5 µg/m³), the estimated annual reductions in total premature deaths would increase to 376,863, 489,528, and 626,157, respectively. The corresponding reductions in cause-specific mortality would range from 116,896 to 200,159 for IHD, 132,123 to 205,449 for stroke, 34,309 to 57,807 for COPD, 12,917 to 24,974 for LRI, and 51,919 to 85,215 for LC.

3.3 Morbidity

Supplementary table 6 presents the annual average estimates of PM_{2.5}-associated morbidity outcomes for the baseline scenario and the projected benefits under improved air quality scenarios. Under the policy scenario, the annual average morbidity benefits included 21,422 fewer cardiovascular disease admissions and 26,545 fewer respiratory disease admissions. These estimates increased to 41,690 and 51,681 cases under the 15 µg/m³ scenario, 51,884 and 64,333 cases under the 10 µg/m³ scenario, and 62,146 and 77,073 cases under the 5 µg/m³ scenario, respectively.

3.4 Economic benefits

Figure 5 illustrates the estimated economic benefits associated with the modelled scenarios under SSP2 at the provincial level. Under the policy scenario, the annual average economic benefits were estimated at \$123.7 billion USD, comprising \$87.5 billion USD from reductions in premature mortality and \$175.5 million USD in annual savings from hospitalisation costs. With the adoption of more stringent air quality targets of 15, 10, and 5 µg/m³, total annual savings were projected to increase to \$ 185.7 billion USD, \$240.7 billion USD, and \$ 306.5 billion USD, respectively. Further, the spatial distribution of economic benefits closely followed PM_{2.5} concentration patterns, with eastern and south-eastern provinces experiencing the most substantial gains, while western regions observed relatively lower benefits. Specifically, in the policy scenario, annual average economic benefits ranged from \$33.9 million USD in Tibet to \$12.5 billion USD in Henan, with other provinces such as Shandong (\$10.6 billion USD) and Hebei (\$7.5 billion USD) also realising substantial economic gains. Under the more stringent targets, average economic benefits across all 31 provinces increased progressively under similar distribution patterns, with projected benefits ranging

from \$0.13 billion USD in Tibet to \$29.7 billion USD in Henan under the most stringent 5 $\mu\text{g}/\text{m}^3$ target.

3.5 Scenario analysis

Supplementary tables 7-10 provide summary estimates of the mortality and morbidity outcomes under different population trajectories. Annual reductions in total premature deaths ranged from 177,857 (under SSP4) to 180,500 (under SSP3) under the policy scenario, aligning closely with the SSP2 "middle of the road" estimates. The average annual reduction in morbidity was highest under SSP3 (48,284 cases) and lowest under SSP5 (47,588 cases). Further reductions in premature deaths were observed when achieving lower PM2.5 targets of 15, 10, and 5 $\mu\text{g}/\text{m}^3$, with estimated reductions ranging from 373,985–379,377 deaths, 485,767–492,843 deaths, and 621,288–630,487 deaths, respectively. Annual reductions in hospitalisations corresponded to 92,661–93,967 cases for 15 $\mu\text{g}/\text{m}^3$, 115,333–116,965 cases for 10 $\mu\text{g}/\text{m}^3$, and 138,159–140,119 cases for 5 $\mu\text{g}/\text{m}^3$. The estimated annual economic benefits under the policy scenario ranged from \$86.9 billion to \$88.1 billion, further increasing to \$184.3 billion–\$186.8 billion for 15 $\mu\text{g}/\text{m}^3$, \$238.9 billion–\$242.2 billion for 10 $\mu\text{g}/\text{m}^3$, and \$304.2 billion–\$308.5 billion for 5 $\mu\text{g}/\text{m}^3$.

4. Discussion

In this study, we modelled the health and economic benefits of air quality improvements in China under several population and PM2.5 concentration scenarios. Our analysis suggested that attaining China's current national policy, which aims to reduce PM2.5 levels by 10% from 2021 to 2025 and reach 25 $\mu\text{g}/\text{m}^3$ by 2030, would prevent an annual average of approximately 179,274 premature deaths and 47,967 hospitalisations, translating to economic benefits totalling \$87.5 billion USD (\$62.5 USD per capita), representing approximately 0.6% of China's national GDP in 2020. Under this policy scenario, the annual average reduction in premature deaths accounted for roughly 10% of the total PM2.5-attributable deaths estimated in 2020. Reductions in deaths from IHD and stroke accounted for most of these benefits, comprising 31.4% and 34.2% of the total annual average averted deaths, respectively. Under the VSL of \$689,659 USD, monetised mortality benefits significantly exceeded savings from reduced hospitalisations, comprising over 99% of total economic gains. The greatest benefits were observed in regions with high PM2.5 concentrations and population densities, such as the BTH, FP, and YDR region. At the provincial level, Shandong, Henan, and Hebei yielded the highest estimated annual benefits, equating to 1.0%, 1.6%, and 1.4% of their respective 2020 GDPs. Moreover, our model estimates suggested substantially greater health and economic benefits could be realised under more stringent air quality targets. Specifically, the additional annual average economic benefits were projected to be approximately 2.1, 2.7, and 3.5 times higher under the 5, 10, and 15 $\mu\text{g}/\text{m}^3$ targets, respectively, compared to the national policy scenario. These results underscore the substantial potential for improved health and economic outcomes through more stringent air quality control, supporting the national government's ongoing efforts to enhance air quality, and emphasising the necessity to set more ambitious future guidelines. Our study contributes to the literature in several ways. First, it provides an updated analysis to support identifying at-risk populations and future policy design by projecting health and economic outcomes in the future at the national level. Limited evidence exists in this area of research. Previously, Wang et al quantified the health benefits for 100% and 50% improvements in air quality based on 2010 levels, reporting a reduction in the number of PM2.5-related premature deaths in China by approximately 129 278 by 2020 and 217 988 by 2030, compared with 2010 [36]. Since then, China has significantly reduced PM2.5 concentrations, with annual average of 32.6 $\mu\text{g}/\text{m}^3$ in 2020. With the introduction of its latest 14th 5-year action plan and healthy 2030 plan, China is set to reach the target of 25 $\mu\text{g}/\text{m}^3$ by 2030 [15]. Additionally, in 2021, the WHO updated its air quality guidelines, recommending several updated interim and final targets to reflect the growing body of updated epidemiology evidence suggesting of the adverse health effects of exposure to PM2.5 at low concentrations [37]. These update in policies and air quality guidelines both nationally and internationally necessitate an updated analysis to support identifying at-risk populations and

informing future policy design. Additionally, in this analysis, we employ the GEMM to estimate mortality. Evidence shows that GEMM predicts mortality estimates over 120% higher than other established exposure-response functions, such as the WHO's Integrated Exposure-Response model or the log-normal model by considering for epidemiological evidence specific to ambient air pollution, as well as including evidence from high pollution regions [24]. Additionally, we also quantified the economic outcome through WTP and COI estimates to facilitate decision making.

Several limitations and future research questions should be acknowledged. As with all modelling analyses, the accuracy of our estimates is constrained by simplifying assumptions. First, we assumed that annual average PM_{2.5} concentrations serve as a proxy for long-term exposure, despite individual exposure being influenced by spatial-temporal variability, socioeconomic factors, and personal health behaviours [38,39]. Second, our economic valuation heavily relied on the VSL estimate, despite the lack of a nationally recognised figure. Previous VSL studies have reported values ranging from \$23,745 USD to \$614,805 USD, highlighting the significant variability [30]. In our analysis, we opted for a recent VSL figure estimated in multiple cities representative of the national population. Third, due to the absence of city-level data on age-specific population trajectories, baseline mortality, morbidity, and healthcare utilisation, we relied on provincial and regional data from statistical yearbooks and national death registries. Fourth, future advancements in healthcare services could significantly alter hospitalisation rates and costs, yet our projections are based on historical trends. Further, a border societal perspective on the benefits of reducing PM_{2.5} could be considered. For example, this study did not incorporate indirect benefits such as avoided productivity losses. Additionally, previous studies have indicated that air pollution mitigation can involve substantial costs, including direct abatement costs and broader social and economic impacts [22,40]. Although these were beyond the scope of this study, they may affect the overall net economic benefit of such policies and warrant further investigation. Lastly, we assumed a steady decline in PM_{2.5} concentrations over our modelled period, while in reality, PM_{2.5} reductions occur through a non-linear process.

5. Conclusion

We modelled the potential health and economic benefits of improving air quality in China from 2021 to 2030. Achieving a 10% reduction in national PM_{2.5} concentrations by 2025, with a target of 25 $\mu\text{g}/\text{m}^3$ by 2030, was estimated to prevent an average of 179,274 premature deaths and 47,967 hospital admissions annually, corresponding to \$87.5 billion USD in annual average economic benefits. However, more ambitious targets could yield substantially greater benefits, with annual death reductions of 376,863, 489,528, and 626,157 and hospitalisation reductions of 93,371, 116,217, and 139,219, under 15, 10, and 5 $\mu\text{g}/\text{m}^3$ targets, respectively, representing a 2 to 3-fold increase compared to the national target. Our findings underscore the substantial additional health and economic benefits of stricter air quality policies and supports the development of future evidence-based national air quality guidelines.

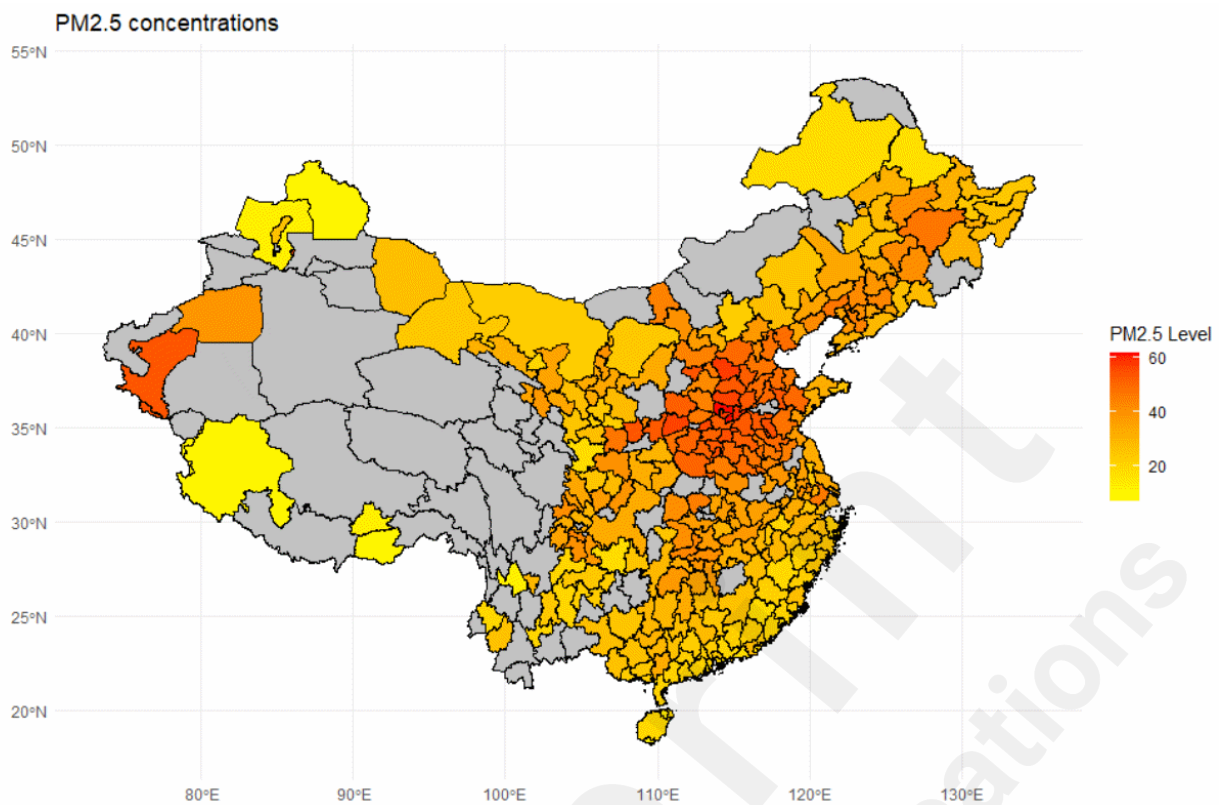


Figure 1. Annual average PM2.5 concentrations in 2020

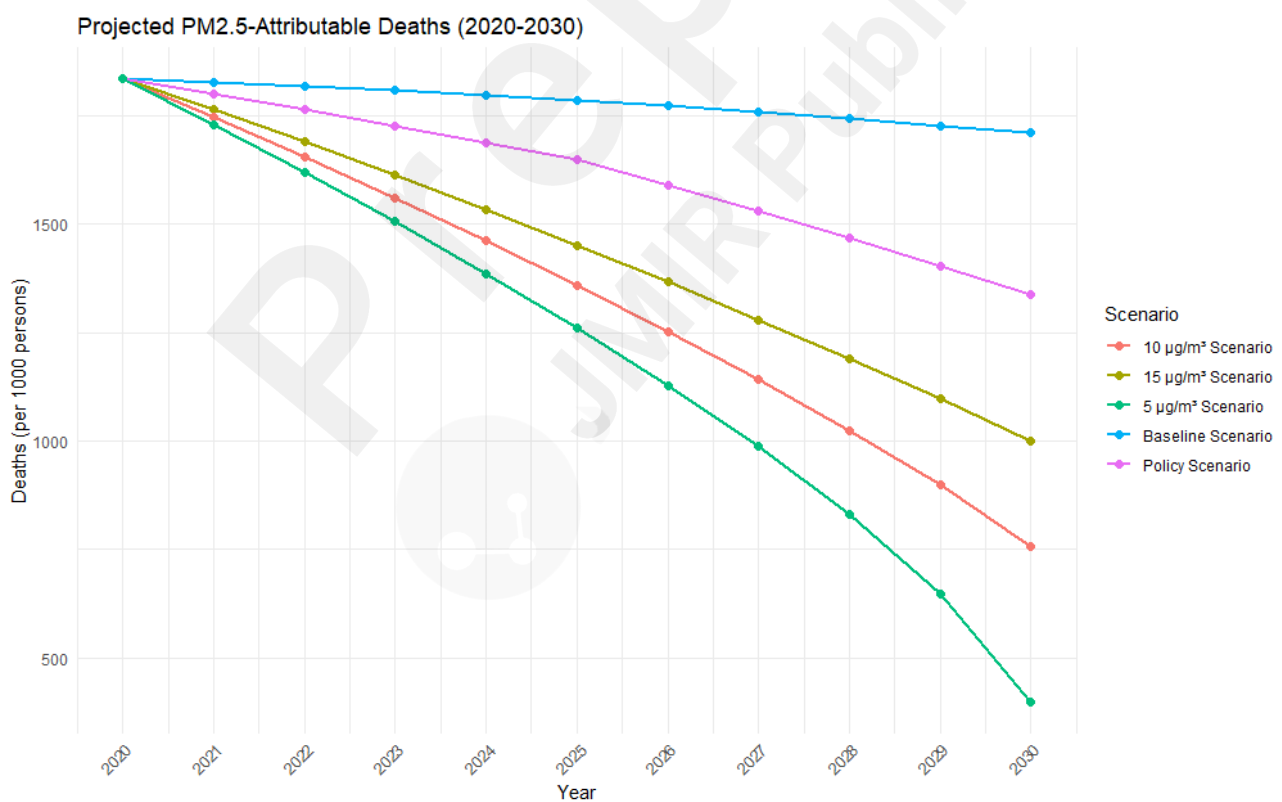


Figure 2. Projected PM2.5-attributable premature deaths (2020–2030)

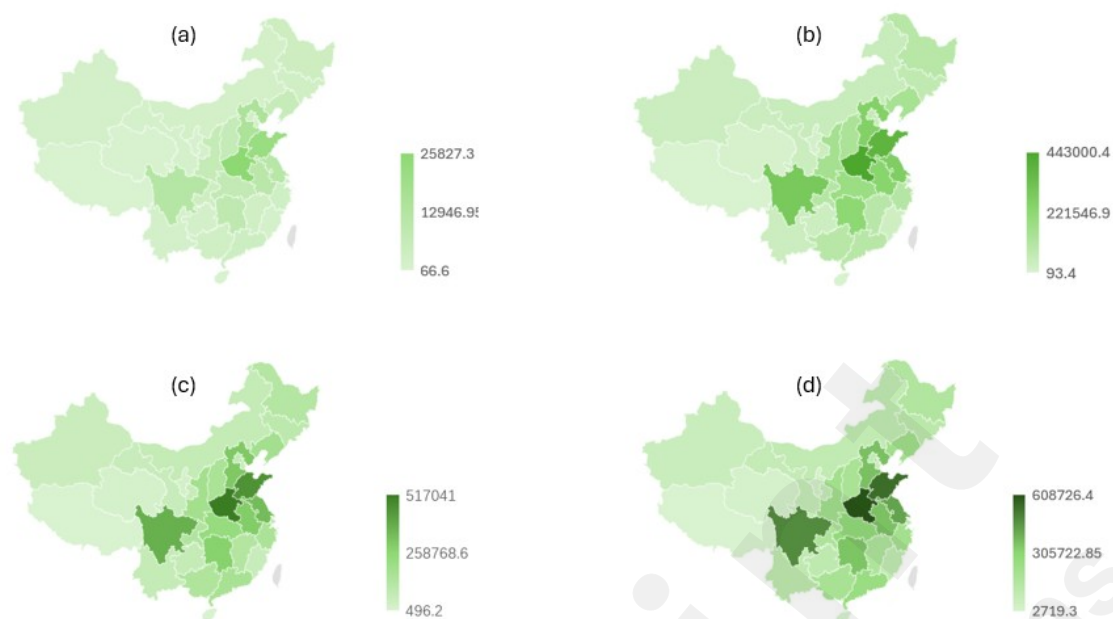


Figure 3. Spatial distribution of reductions in PM_{2.5}-attributable premature death under improved air quality. a) Policy scenario; b) 15 µg/m³ target; c) 10 µg/m³ target; and d) 5 µg/m³

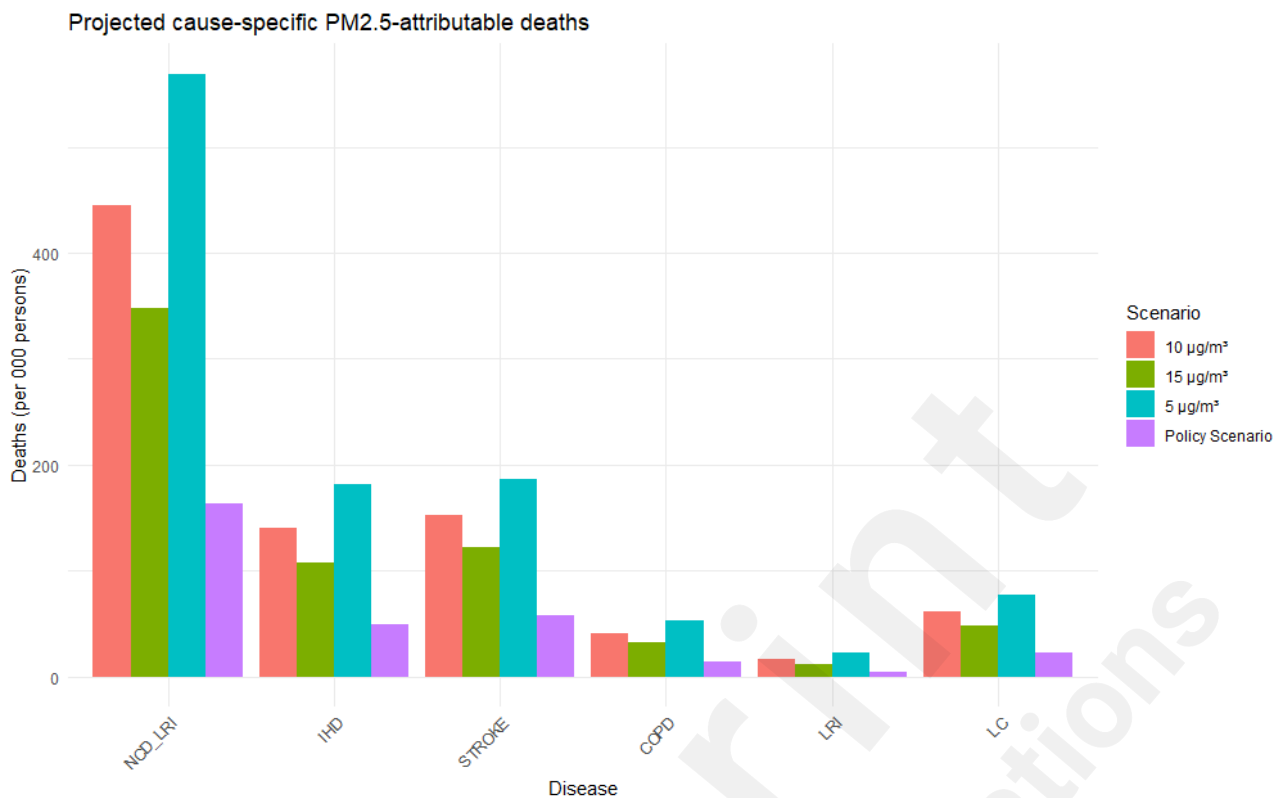


Figure 4. Projected annual average premature deaths by cause under improved air quality scenarios

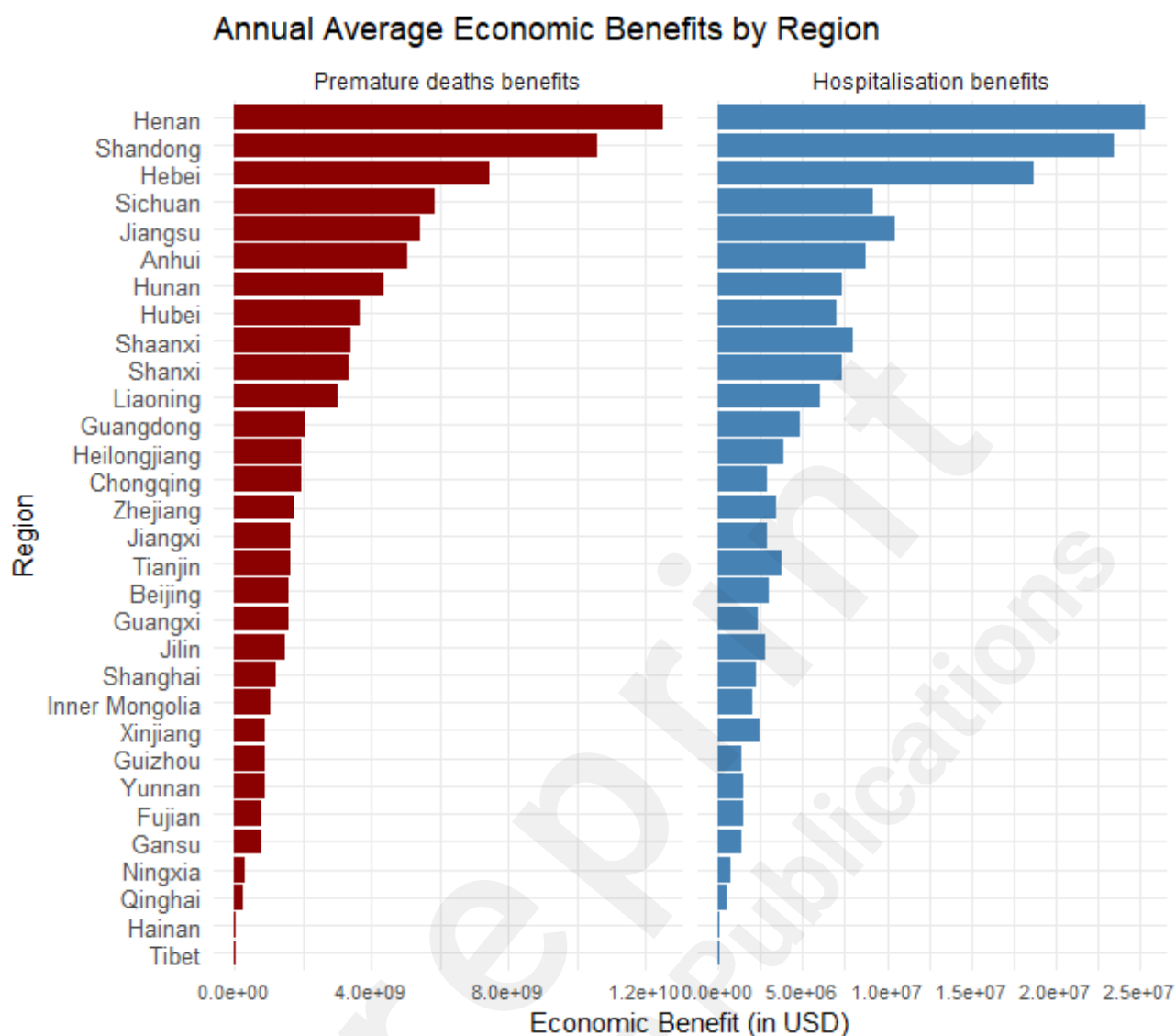


Figure 5. Estimated mortality and morbidity benefits by provinces under “Policy scenario”

Declarations

Funding: This study was funded by the National Natural Science Foundation of China (grant number: 71874086, 72174093, 72474109).

Conflict of interest: None declared.

Data Availability: The datasets generated or analysed during this study are available from the corresponding author on reasonable request.

Authors' Contributors: Conceptualization: SW, LS, MC; Data curation: SW, LS; Formal analysis: SW, LS; Methodology: SW, ZX, SL, SJ; Writing – original draft: SW; Writing – review & editing: SW, LS, MC, ZX, SL, SJ; Resources: MC, LS; Supervision: LS. SW is responsible for the overall content as guarantor. All authors critically reviewed the manuscript and approved the final version prior to submission and resubmission.

Abbreviations

Beijing-Tianjin-Hebei (BTH)

Cost-of-illness (COI)

Chronic Obstructive Pulmonary Disease (COPD)

Cardiovascular Disease (CVD)

Disability-adjusted life years (DALYs)

Fenwei Plain (FP)
Global Exposure Mortality Model (GEMM)
Ischemic heart disease (IHD)
Lung cancer (LC)
Lower respiratory infection (LRI)
Non-communicable diseases (NCD)
Particulate matter (PM)
Shared Socioeconomic Pathways (SSP)
Value-of-statistical life (VSL)
World Health Organisation (WHO)
Willingness to pay (WTP)
Yangtze Delta (YRD)
Years of life lost (YLL)

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Supplementary Files

Multimedia Appendixes

Online supplementary material.

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