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从公共健康视角看空气质量管理与气候变化：加州和中国的政策与技术选项

The Public Health Dimensions of Air Quality and Climate Change: Highlights of Policy and Technological Options from California and China

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About the California-China Climate Institute

The California-China Climate Institute was launched in September 2019 and is a University of California-wide initiative housed jointly at UC Berkeley's School of Law (through its Center for Law, Energy, and the Environment) and the Rausser College of Natural Resources. It is Chaired by Jerry Brown, former Governor of the State of California, and Vice-Chaired by the former Chair of the California Air Resources Board Mary Nichols. The Institute also works closely with other University of California campuses, departments, and leaders. Through joint research, training, and dialogue in and between California and China, this Institute aims to inform policymakers, foster cooperation and partnership and drive climate solutions at all levels.

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SUMMARY FOR POLICYMAKERS

Air pollution and climate change are linked issues with overlapping solutions and significant public health co-benefits. The connection between air pollution and climate change necessitates a cohesive policy approach to maximize health co-benefits and avoid unintended trade-offs.

Both California and China can achieve great health co-benefits through continued greenhouse gas emissions reduction and improved air quality in their jurisdictions. By synergistically addressing the issues of air pollution and greenhouse gas emissions, policymakers can successfully enhance public health outcomes.

Public Health Co-benefits

Lower Mortality and Morbidity, and Socioeconomic Benefits

A growing body of literature has shown that air pollution and climate change contribute to disease morbidity. Therefore, effective air and climate policies have the potential to lower global mortality and morbidity rates. Moreover, as the burden of air pollution and climate change is unequally distributed across populations and communities, addressing air and climate problems will have larger public health co-benefits in vulnerable populations and disadvantaged communities. In addition, air and climate policies deliver socioeconomic benefits through improved public health outcomes. Recent studies show that effective air and climate policies can reduce health expenditures and foster human capital through increased productivity. Both California and China will economically benefit from public health improvement.

Public Health Indicators and Available Monitoring Technologies

Indicators help track momentum toward improved public health outcomes and enable jurisdictions to assess progress over time. Two major types of policy indicators are mortality and morbidity. Other indicators are socioeconomic; examples are indicators such as household medical expenditures, labor productivity loss, and community vulnerability. Given scientific uncertainties, public health policy indicators need to be revised and improved in the future.

In addition, technology aids in monitoring and analyzing public health indicators. Technical tools such as satellite-based remote sensing, air quality monitoring networks, and machine learning allow scientists and policymakers to measure climate health indicators with greater accuracy and granularity.

Best Practices in California and China

Both California and China have ambitious air quality and climate targets and have been implementing various types of policies to achieve their goals. California has integrated public health into its air and climate policies, primarily by incorporating public health indicators in policies, establishing public health monitoring networks, and measuring implementation action. More attention has been paid to vulnerable populations in recent years to address environmental justice issues. Meanwhile, China is now a pioneer in mitigating air pollution and greenhouse gas emissions simultaneously. China has established a large-scale air quality monitoring program, as well as a comprehensive policy framework for climate change mitigation. Even though public health has not yet been a motivation for China's greenhouse gas policies, public health has been emphasized in climate adaptation policies, and efforts to assess the health impacts of climate change have been seen in several Chinese provinces.

Both jurisdictions provide good examples. Los Angeles successfully combines scientific research with policymaking and integrates public health indicators in its air and climate policies. Similarly, Beijing and Shenzhen are actively devising public health indicators and further controlling air pollution and greenhouse gas emissions by implementing “coordinated control” policies and carbon markets.

Lessons Learned

Important lessons can be gleaned from considering the public health co-benefits of air pollution and climate actions concurrently. California has demonstrated that public health co-benefits can serve as measurable, quantitative goals within climate and air quality policies. California has also made significant progress in incorporating environmental justice considerations into its work. On the other hand, China has excelled at developing highly sophisticated air quality monitoring tools and a comprehensive climate policy framework, and should further integrate public health indicators in its policies. Case studies from jurisdictions like Los Angeles, Beijing, and Shenzhen shed insights into real-world examples of how cities are considering air quality and climate change in tandem.

This report also identifies several key opportunities for moving forward: (1) Convene exchanges and training between jurisdictions in California and China to share lessons learned; (2) Utilize, replicate, and expand upon the use of technological monitoring and mapping tools; (3) Further implement “coordinated control” and regional management approaches; (4) Conduct more localized public health research; (5) Enhance the role of multi-stakeholder engagement in driving public health actions; and (6) Prioritize public health in air and climate policymaking agendas.

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ABBREVIATIONS AND ACRONYMS

AB 32	Global Warming Solutions Act (Assembly Bill 32)
AQI	Air Quality Index
AQ-SPEC	Air Quality Sensor Performance Evaluation Center
BenMAP	Environmental Protection Agency's Environmental Benefits Mapping and Analysis Program
BMDRC	Beijing Municipal Development and Reform Commission
BMHC	Beijing Municipal Health Commission
BMEEB	Beijing Municipal Ecology and Environment Bureau
BVOCs	Biogenic volatile organic compounds
CAA	Clean Air Act
CAAQS	California Ambient Air Quality Standards
CARB	California Air Resources Board
CDC	Center for Disease Control
CEMO	Climate Emergency Mobilization Office
CEPHT	Chinese Environmental Public Health Tracking system
CH_4	Methane
CO	Carbon monoxide
CO_2	Carbon dioxide
COPD	Chronic Obstructive Pulmonary Disease
CSULA	California State University Los Angeles
EPA	Environmental Protection Agency
F-gases	Fluorinated gases
FYP	Five-Year Plan
GDP	Gross domestic product
GHG	Greenhouse gas

ABBREVIATIONS AND ACRONYMS (CONT.)

LARC	LA Regional Collaborative for Climate Action
MATES	Multiple Air Toxics Exposure Study
MEE	Chinese Ministry of Ecology and Environment
NAAQS	National Ambient Air Quality Standards
NASA	National Aeronautics and Space Administration
NH_4	Ammonia
NOx	Nitrogen oxides
OEHHA	(California) Office Environmental Health Hazard Assessment
Pb	Lead
PLACE	Policies for Livable Active Community and Environment
PM (2.5 or 10)	Particulate matter (with diameters that are generally 2.5 or 10 micrometers and smaller)
PPM	Parts per million
SB 32	California Senate Bill 32
SCAQMD	South Coast Air Quality Management District
SEZ	Special Economic Zone
SIP	State Implementation Plan
SLCPs	Short-lived climate pollutants
SMBEE	Shenzhen Municipal Bureau of Ecology and Environment
SMHC	Shenzhen Municipal Health Commission
SOx	Sulfur oxides
U.S.	United States
VOCs	Volatile organic compounds
VSL	Value of a Statistical Life
WHO	World Health Organization
YLL	Years of Life Lost
$\mu g/m^3$	Micrograms per cubic meter
μm	Micrometers

1. OVERVIEW

Both California and China stand to achieve significant health co-benefits through the continued reduction of greenhouse gases (GHGs) and the improvement of air quality in their jurisdictions. The link between air pollution and climate change necessitates a cohesive approach to policy implementation to maximize co-benefits and avoid unintended trade-offs. By synergistically addressing these issues, policymakers can enhance public health outcomes and meet climate and air quality commitments at the same time.

Exploring the public health co-benefits of tackling air quality and climate policies in tandem, this report utilizes a literature review and policy analysis, and an overview of key indicators and technologies in key urban regions in California and China. Additionally, it includes examples of these synergies in practice from Los Angeles, Beijing, and Shenzhen, and provides key lessons learned.

Yet, China and California have vastly different industries and laws, and rely on different fuels, thus the source, amount, and concentration of emissions vary significantly between the two. California is the most populous state in the United States (U.S.) and the fifth-largest economy in the world. It is also home to seven out of ten U.S. cities with the highest concentrations of fine particulate matter, and a significant number of U.S. cities with the highest concentrations of ozone (ozone).[1] Air pollutants in California are mostly from area-wide, mobile, and natural sources like vehicle emissions, secondary aerosols, soil, agriculture, and industrial emissions.[2]

Meanwhile, in China, between 2002 and 2017, its gross domestic product (GDP) grew by 284%, which led to the nation becoming the largest global energy consumer, bringing severe air pollution and carbon dioxide (CO_2) emissions growth.[3] Heavy industry, including coal-fired power plants, were the backbone of this large-scale growth, and remain a major contributor of GHGs in China.

Section 1 of the report provides an overview of the report's context and structure. Section 2 details the importance of linking air quality, climate policy, and public health and provides an academic literature review. Section 3 provides an overview of policies and programs to synergize the public health co-benefits of climate and air quality actions in California and China. Section 4 summarizes key indicators of public health co-benefits from these actions, while Section 5 explores technological approaches used in both jurisdictions. Section 6 dives into practical cases from urban areas in California and China, giving examples of synergies in practice. Section 7 provides our recommendations.

1 American Lung Association. (n.d.).

2 Aguilera et al. (2021); Anderson et al. (2018).

3 Geng et al. (2021); Shi et al. (2022).

2. THE IMPORTANCE OF LINKING AIR QUALITY, CLIMATE POLICY, AND PUBLIC HEALTH

2.1 The Nexus of Air Pollution, Climate Change, and Public Health

Air pollution and climate change—while often addressed separately—are intertwined. Both are driven by burning fossil fuels and are harmful to public health.[4] Climate mitigation policies focused on reducing coal and GHGs can have substantial co-benefits for air quality and public health.[5] Climate policies tend to focus on reducing carbon dioxide (CO_2) emissions, but can also limit co-emitted air pollutants such as nitrogen oxides (NO_x), particulate matter (PM), ammonia (NH_4), and sulfur oxides (SO_x).[6] Conversely, air quality policy can promote the mitigation of GHGs by affecting local energy systems through caps on energy use and energy efficiency improvements.[7] Air quality policies may also target chemicals that contribute to climate change, such as ozone, sulfates, and black carbon.[8]

Air pollution is the contamination of air by solid, liquid, and gaseous airborne particles.[9] In the U.S., under the Clean Air Act—the county's primary air pollution policy—the Environmental Protection Agency (EPA) regulates six "criteria air pollutants," which include carbon monoxide (CO), lead (Pb), NO_x, ozone, and particulate matter.[10] China's most recent national air quality standards, set and regulated by the Ministry of Ecology and Environment (MEE), similarly regulate particulate matter, NO_x, ozone, CO, Pb, and sulfur dioxide (SO_2).[11]

The current academic literature suggests that particulate matter and ozone are most harmful to human health.[12] Particulate matter is categorized into PM_{10} and $PM_{2.5}$, with PM_{10} defined as particles that are less than or equal to 10 micrometers in diameter and $PM_{2.5}$ as particles less than or equal to 2.5 micrometers in diameter. Both PM_{10} and $PM_{2.5}$ are mixtures of solid and liquid substances that can include sulfate, nitrate, ammonium, organic carbon, sea salt, and dust.[13] Even in small concentrations, each has serious health implications, but the smaller size of $PM_{2.5}$ allows the particle to settle deeper in the body and has been associated with early mortality, lung cancer, heart conditions, strokes, and asthma.[14] Ozone, which is formed through the chemical reaction of sunlight, NO_x, and volatile organic compounds (VOCs), is a key component of smog, and has been linked with early mortality, lung disease, and asthma.[15] Climate change is expected to exacerbate ozone pollution in the U.S., since increasing temperatures will accelerate ozone production.[16] Mortality associated with $PM_{2.5}$ and ozone are the largest contributors to the economic health impacts of air pollution in the U.S., with current research suggesting that $PM_{2.5}$ has the largest global impact on air pollution-related mortality and costs.[17]

4 Bollen et al. (2009).

5 Anderson et al. (2018); Tong et al. (2021); T. Wang et al. (2020); B. Zhao et al. (2019).

6 Bollen et al. (2009); Fuller et al. (2022); T. Wang et al. (2020).

7 Shi et al. (2022).

8 USGCRP (2016).

9 Fuller et al. (2022).

10 Clean Air Act (1963).

11 Ministry of Ecology and Environment (2012).

12 Anderson et al. (2018); T. Wang et al. (2019, 2020).

13 USGCRP (2016).

14 Anderson et al. (2018); USGCRP (2016); Williams & Phaneuf (2019).

15 Anderson et al. (2018); USGCRP (2016).

16 USGCRP (2016).

17 Anderson et al. (2018); T. Wang et al. (2019); Zhao et al. (2019).

Beyond $PM_{2.5}$ and ozone, NO_2 also has been scientifically linked to mortality and morbidity, while ultrafine or nanoparticles (defined as particles less than 0.1 micrometers in diameter) are potentially more harmful to human health than PM_{10} and $PM_{2.5,}$ yet are not routinely monitored or regulated.[18] Short-lived climate pollutants (SLCPs) such as methane (CH_4), black carbon, and fluorinated gases (called F-gases, and including hydrofluorocarbons) are also harmful to the climate and human health, as they are more potent GHGs than carbon dioxide.[19]

The health impacts of air pollution and GHG emissions depend on several factors, including the source of pollution, the amount of emissions, the pollutant's air concentration, the source of exposure, and the amount of particles absorbed from both the inhalation rate and particle size.[20] Both primary (emitted) and secondary (formed) pollutants are important factors in driving public health outcomes.[21] This report focuses foremost on outdoor air pollution; however, indoor air quality is also an important consideration, since people spend most of their time indoors.[22] Outdoor air pollution, by definition, can extend beyond geographic borders, complicating efforts to measure and assess its effects.

The risk factors for climate change, such as local emission sources and local ecologies, do not exist in isolation, thus many populations will face simultaneous increases in exposure to both heat and air pollution.[23] Another factor to consider in the nexus between public health, air pollution, and climate change is the co-exposure to other climate change effects; for example, heat. Extreme heat—including heat waves —has become more intense and frequent across the globe, and poses a major threat to human life, exacerbating cardiovascular and respiratory diseases and mortality.[24] In a recent study, Rahman et al. found that the excess mortality risk associated with co-exposure to extreme heat and $PM_{2.5}$ was approximately three times larger than the estimated effects of exposure to one dimension alone.[25] These synergistic effects between extreme heat and $PM_{2.5}$ also have been reported with heat and ozone.[26] One reason for this co-exposure could be that heat wave-related high temperatures increase the emission rates of biogenic volatile organic compounds (BVOCs) discharged by plants, which augment the production of ozone and $PM_{2.5}$.[27] The co-exposures of extreme temperatures and poor air quality are becoming more frequent, longer-lasting, and more impactful to public health.[28]

2.2 Literature Review

Addressing the health impacts of air pollution and climate change is critical. This review explores recent studies at the intersection of air quality, climate policy, and public health co-benefits. By definition, co-benefits relate to actions in multiple areas, and it is important to note that progress in one area has the potential to influence other dimensions.[29] This review addresses the key considerations of co-benefits of air pollution and climate change actions: human mortality, morbidity, and socioeconomic impacts.

Mortality

A growing body of research has shown that air pollution and climate change contribute to premature death. The World Health Organization (WHO) estimates that 4.2 million premature

18 Tian et al. (2022); Wing et al. (2020, p. 20).

19 California Air Resources Board (2022a).

20 Smith (1988).

21 California Air Resources Board (2022a).

22 USGCRP (2016).

23 Anenberg et al. (2020).

24 IPCC AR6 Working Group 1 (n.d.); Rahman et al. (2022); Schnell & Prather (2017); Watts et al. (2021).

25 Rahman et al. (2022).

26 Anenberg et al. (2020).

27 Schnell & Prather (2017).

28 Schnell & Prather (2017).

29 California Air Resources Board (2022a).

deaths were attributed to ambient air pollution in 2019 alone, rising from 3.7 million attributable premature deaths in 2012.[30] About 1 million of these deaths are tied to emissions from coal, with a 2018 study attributing 12% of global $PM_{2.5}$-related deaths to emissions from fossil fuel and biomass-fired power plants.[31]

Effective climate and air quality policies have the potential to impact global mortality rates, with Markandaya et al. (2018) finding that if the 2 degrees Celsius (2°C) global temperature goal is met, a 21%–27% reduction in rates of premature death could be achieved. This is crucial for China, which is predicted to have the largest proportion of premature deaths related to climate change between 2020–2050, projected to account for 33%–37% of global deaths attributable to climate change in that time frame.[32] Xie et al. (2020) argue that improved air quality mitigation focused on reducing ambient $PM_{2.5}$ exposures could avoid 370,000 premature deaths by the 2050s. Zhang et al. (2021) assess that if carbon neutrality goals are realized, air quality in all provinces in China could meet the 2005 WHO $PM_{2.5}$ standards (10 micrograms per cubic meter [$\mu g/m^3$]) by 2060. This could lead to China preventing 22–50 million cumulative premature deaths between 2020 and 2060, with the authors extrapolating that it could potentially increase associated life expectancy by 0.88–2.80 years per person in 2060.[33]

Vulnerable populations, such as racial minorities, women, children, the elderly, smokers, diabetics, and those with prior heart disease, are more sensitive to both indoor and outdoor air pollution,[34] with a particular sensitivity to PM exposure.[35] For example, compared to younger age groups, people over the age of 65 are generally more vulnerable to the health risks of climate change,[36] as climate change can aggravate the problem of air pollution by increasing ozone levels or causing more wildfires.[37] The mortality rate attributed to indoor air pollution among this age group is 4–7 times higher than in all other ages, and one study found that during wildfire days in the Western U.S., there was a 7.2% increase in elderly hospital admissions.[38]

Morbidity

Both air pollution and GHGs are mainly inhaled into the lungs, and it is proven that air pollutants could exacerbate the consequences of diseases that affect the respiratory system (including COVID-19) but also affect the cardiovascular system.[39] A 2017 study on $PM_{2.5}$ associated with California's wildfires found that high exposure to air pollution from wildfires was consistently related to increases in emergency department visits for respiratory disease, asthma, chronic lower respiratory disease, and acute myocardial infarction.[40] Allergies also have been associated with climate change, as anthropogenic CO_2 emissions promote growth and longer growing seasons for plants that produce and distribute allergens.[41] Meanwhile, all criteria pollutants defined by the EPA affect respiratory morbidity, while ozone and CO exposure are associated with an elevated risk of cardiovascular morbidity.[42] A study in China predicted that stringent policy on reducing annual ambient $PM_{2.5}$ exposure could avoid 11.3 million cases of morbidity globally by 2050, mainly due to a reduction in asthma attacks and hospital admissions.[43]

30 World Health Organization (2022); Chen et al. (2020).

31 Tong et al. (2018); Watts et al. (2021).

32 Markandya et al. (2018).

33 S. Zhang et al. (2021).

34 Tibuakuu et al. (2018).

35 USGCRP (2016).

36 Cai et al. (2022); Yu et al. (2019).

37 Heaney et al. (2022); Schwarz et al. (2021).

38 Liu et al. (2017); Yu et al. (2019).

39 Malig et al. (2021); Wu et al. (2020).

40 Malig et al. (2021).

41 Anenberg et al. (2020); Strain (1987); USGCRP (2016).

42 Williams & Phaneuf (2019).

43 Xie et al. (2020).

Climate change and air pollution are complex and multi-dimensional issues. Depending on the characteristics of the emission and its source, air pollutants will affect individuals differently, but several studies have highlighted that the most vulnerable populations include women, neonatal infants, and the elderly. Studies have found links between pregnant women exposed to air pollution with infertility issues and adverse birth outcomes, including low birth weight and preterm birth.[44] Several studies focused on proximity to traffic-related air pollution, finding that adjacency, as well as high levels of CO and PM, were associated with negative birth outcomes.[45] Another study looked at the proximity of residents to oil and coal power plants in California and found that close proximity to these sites, which can release a variety of pollutants including benzene and lead, was associated with preterm birth.[46]

Air pollution and climate change are unequally distributed across vulnerable populations. Different emission sources and ambient concentrations burden some communities over others, with race/ethnicity, socioeconomic status, and access to healthcare contributing to this inequity.[47] Thus, it is important to ensure dedicated resources available to these vulnerable communities. In 2012 and 2016, California passed Senate Bill 535 (SB 535) and Assembly Bill 1550 (AB 1550) to direct investments to disadvantaged communities to improve public health, enhance economic opportunities, and mitigate the impact of air pollution and climate change.[48] Recent California climate change mitigation law, including Senate Bill 32 (SB 32), specifies that disadvantaged communities, which are designated based on community air quality and demographics, should not unequally bear the air pollution burden due to GHG reduction policies such as Cap-and-Trade.[49] Another emerging field is the association between air pollution, climate change, and mental health. For example, increases in $PM_{2.5}$ are associated with declines in mental health levels.[50]

Socioeconomic Co-benefits: Avoided Mortality and Morbidity

Socioeconomic co-benefits of successful climate and air policy include reduced mortality and health expenditures, as well as fostering human capital through increased productivity and educational attainment. A study found that a one standard deviation increase in $PM_{2.5}$ increases asthma and chronic obstructive pulmonary disease (COPD) spending by more than 12.7%, representing over $9 billion in annual expenditures compared to 2012 levels.[51] Meanwhile, it is estimated that California's 2018 fire season resulted in a $32.2 billion loss, attributed to the value of statistical life (VSL) applied to the 3,653 air pollution deaths correlated with the wildfires.[52] Another study applied forecasting in the wider U.S. and found that climate change mitigation could avoid more than 10,000 premature deaths in 2050 and 5,000 premature deaths in 2100 due to air quality improvements; equivalent to a VSL of approximately $150 billion (in 2005 dollars) by 2050 and $1.3 trillion by 2100.[53]

China could experience similar economic co-benefits from climate mitigation, with modeling showing that the co-benefits could be even more significant in East Asia than in any other region. The study compared the marginal costs of emissions reductions in 13 models with VSL and found that the co-benefits in East Asia are between 10–70 times higher than the marginal cost in 2030.[54] Another study showed that China's climate change mitigation actions could benefit populations beyond the nation's borders, as the reduction of $PM_{2.5}$ concentrations associated

44 Nieuwenhuijsen et al. (2014); X. Wang et al. (1997); Wilhelm et al. (2012); Wing et al. (2020).

45 Coker et al. (2016); Wilhelm et al. (2012).

46 Casey et al. (2018).

47 T. Wang et al. (2020).

48 California Office of Environmental Health Hazard Assessment (n.d.).

49 Anderson et al. (2018).

50 T. Xue et al. (2019).

51 Williams & Phaneuf (2019)

52 Wang et al., 2021

53 Garcia-Menendez et al. (2015).

54 West et al. (2013).

with climate mitigation could avoid global expenditures of about $406 billion and $1,206 billion due to premature death by the 2030s and 2050s.[55] The co-benefits from China's climate mitigation actions could include health expenditure savings, by decreasing air pollution-related morbidity and mortality costs.

Air pollution and climate change events, such as heat waves or extreme weather events, can affect productivity and school attendance, thus the improvement of air quality could lead to fewer work and school time losses.[56] Air pollution has been linked to respiratory illnesses, and may affect children's cognitive abilities and physical health, which may in turn have long-term impacts on education, earnings, and human capital.[57]

Knowledge Gaps

Despite the significant body of literature on the health impacts of climate and air policy, there are still several gaps in air pollution research. One such gap is the underestimation of air pollutant toxicity. For instance, while the composition of PM can vary, all PM is treated as equally toxic, despite scientific efforts to identify which components and sources are the most harmful to health. This issue should therefore be targeted by policy actions.[58]

While much of the academic research is centered on single exposure, co-exposure is an emerging research area, as there is increasing recognition that humans are typically exposed to a mixture of both pollutants and environmental stressors.[59] While there is substantial evidence on the health effects of $PM_{2.5}$ and ozone as individual pollutants, there are fewer studies on their synergistic effects.[60] Environmental stressors also can be considered co-exposures to air pollutants, and climate change projections indicate more frequent heat waves overlapping with high pollution days and wildfire smoke.[61] However, the relationship between climate change and air pollution is complex, with ongoing debate over whether climate change will lead to a net decrease or increase of $PM_{2.5}$ in the U.S. Additionally, there is no consensus on which pollutant will be the dominant driver of air quality-related health effects attributable to climate change.[62]

Meanwhile, technological solutions for assessing pollution, tracking emissions sources, and measuring disease all can prove supportive tools to achieve the health co-benefits of climate actions. Section 5 of this report details a set of digital technologies and tools that can support GHG emissions reductions and combat air pollution concurrently, but additional research in this domain would prove beneficial.

Despite these uncertainties, addressing the health co-benefits of air quality and climate policy is significant, and this report analyzes the current policy portfolio in California and in China to inform evidence-based policymaking that takes into account the co-benefits of addressing climate change, air quality, and public health together.

55 Markandya et al. (2018).

56 Xie et al. (2020).

57 Allen et al. (2017); S. Chen et al. (2018); Sunyer et al. (2015); X. Zhang et al. (2018).

58 Kelly & Fussell (2020).

59 Guarnieri & Balmes (2014).

60 Q. Ma et al. (2020).

61 Rahman et al. (2022).

62 USGCRP (2016).

3. POLICY APPROACHES TO PUBLIC HEALTH CO-BENEFITS OF AIR AND CLIMATE POLICIES IN CALIFORNIA AND CHINA

Both California and China have ambitious air quality and climate targets and have been implementing various types of policies to achieve their goals. This section provides an overview of what policy instruments California and China are adopting to achieve the synergy between air quality, climate change mitigation, and public health benefits. It also summarizes existing gaps in current policies in both jurisdictions.

3.1 The California Approaches

California has long been seen as a leader in fighting air pollution and climate change.[63] Public health has been integrated into the climate and air quality policy in California, primarily by motivating policymaking and measuring the implementations. In recent years, vulnerable populations such as children and environmental justice communities have received more attention in California's climate and air policy. This section briefly summarizes and highlights synergies between public health, air quality, and climate change.

TABLE 1 | Summary of California's State Implementation Plan[64]

Year Published	**2022**
Purpose	Provides a plan for the attainment of ozone NAAQS under the federal Clean Air Act
Main Goals	• To develop control measures and reduce emissions to meet the federal 70 parts per billion (ppb) 8-hour ozone standard, which will also support the attainment of other ozone and fine particulate ($PM_{2.5}$) NAAQS • Reduce health risk in California's most impacted communities.
Measures	• Cut pollution from on-road vehicles such as cars, trucks, and motorcycles by implementing regulations and promoting new emission standards. • Cut pollution from off-road vehicles and equipment through amendments to current policies and standards, as well as designing measures for the aviation and shipping industry. • Other measures are aimed at enhancing air quality through regulations on consumer products, zero-emission standards for heaters, improved regional emission analysis, and health risk mitigation for certain pesticides.

California's Air Quality Policies and Actions

State Implementation Plan

California's master plan to tackle air quality issues resonated in its *State Implementation Plan* (SIP), which outlines how the state will attain the required *National Ambient Air Quality Standards* (NAAQS) under the federal *Clean Air Act*.[65] Table 1 below provides a brief summary of California's latest SIP. It should be noted that local air quality management districts in California are in charge of controlling stationary air pollution sources, and the state-level SIP is developed

63 Keeth (2003).

64 California Air Resources Board (2022a).

65 Clean Air Act (1963).

to implement the air pollution control strategies of those non-attainment regions, adding to local plans and guiding local enforcement.[66]

The promotion of public health benefits is an explicit goal of California's SIP. Since the SIP seeks to implement the Clean Air Act, the plan adopts the Clean Air Act's purpose of improving air quality to protect "public health and welfare."[67] This goal is further elaborated in California's Code of Regulations, which states that the objective of California's Ambient Air Quality Standards (CAAQS), some of which are more stringent than the NAAQS, is "to provide a basis for preventing or abating the effects of air pollution, including effects on health, esthetics, and economy." The CAAQS thus map out the relevant concentrations of air pollutants and their resultant impacts on human health. For example, concentrations of ozone beyond 0.09 parts per million (ppm) for 1 hour and 0.070 ppm for 8 hours may result in lung function deterioration, respiratory irritation, airway hyperreactivity, and inflammation, as well as excess deaths, hospitalization, emergency room visits, asthma exacerbation, respiratory symptoms, and restrictions in activity. Similar impacts are also calculated for substances such as CO, SO_2, visibility-reducing particles, PM_{10} and $PM_{2.5}$, lead, hydrogen sulfide, NO_x, sulfates, and vinyl chloride.[68]

Reducing Air Pollutant Emissions

Most of California's measures to implement the NAAQS and CAAQS are focused on reducing air pollutant emissions. Some of these measures have public health as an explicit goal.

California has implemented several regulations and programs to reduce air pollutants. One is the *Commercial Harbor Craft Regulation*, which aims to replace older engines in commercial harbor craft vessels with newer, cleaner ones to reduce pollutants and protect the health of workers and passengers onboard.[69] Another example is California's *Goods Movement Emission Reduction Program*, which aims to quickly reduce air pollution emissions and health risks from freight movement in California.[70] Similarly, the California Air Resources Board's (CARB's) *Zero-Emission Vehicle Program* is part of California's strategy to meet air quality and GHG emission targets.[71] Additionally, the *Carl Moyer Air Quality Standards Attainment Program* generates revenue through smog abatement fees and surcharges on vehicle registration and tire fees, with a focus on mitigating air pollution's impact on public health, especially in disproportionately affected communities in the San Joaquin Valley.[72] Last but not least, the *Air Cleaner Regulation*, which is under CARB's *Indoor Air Program*, sets an ozone emission limit of 0.050 ppm for portable indoor air cleaning devices in California, given that ozone is harmful to health.[73] These efforts collectively contribute to improving air quality and reducing emissions in California.

California's most recent air pollutant emission reduction programs focus on improving the public health of overburdened communities, including low-income communities and communities of color. Assembly Bill 1749, passed in September 2022, mandates that CARB identify measures in its statewide strategies to reduce toxic air contaminants and criteria air pollutants, aiming to alleviate cumulative exposure burdens in overburdened communities.[74] Senate Bill 1382, also passed in September 2022, updates the *Clean Cars 4 All Program* to reduce GHG emissions and enhance air quality for low-income residents by replacing high-polluting motor vehicles with cleaner and more efficient ones. This bill emphasizes collaboration among CARB, local air districts, and community organizations to address barriers and improve outreach to underserved

66 California Air Resources Board (2022a, p. 10).

67 Clean Air Act (1963).

68 Ambient Air Quality Standards (n.d.).

69 California Air Resources Board (n.d.-a).

70 California Air Resources Board (n.d.-b).

71 California Air Resources Board (2022b).

72 Assembly Bill 2836 (2022); Assembly Bill 1274 (2017).

73 Assembly Bill 2276 (2006).

74 Assembly Bill 1749 (2022).

communities, acknowledging that air pollution disproportionately affects communities of color.[75] These measures underscore California's commitment to addressing environmental disparities and promoting public health in vulnerable communities.

Air Quality Reporting and Monitoring

Table 2 below provides a summary of some California air quality policies that focus on the reporting and monitoring of air pollution: the *Community Air Protection Program* and the *Regulation for the Reporting of Criteria Air Pollutants and Toxic Air Contaminants*.

TABLE 2 | Summary of California's Air Quality Policies on Reporting and Monitoring of Air Pollution[76]

Policy	Community Air Protection Program	Regulation for the Reporting of Criteria Air Pollutants and Toxic Air Contaminants
Year Enacted	**2018**	**2020**
Main Goals	• Reduce exposure in communities most impacted by air pollution.	• Implement statewide annual reporting of criteria air pollutant and toxic air contaminant emissions data from facilities.
Main Tasks	• Measure air pollution via community air monitoring. • Reduce health impacts via community emissions reduction programs. • Address localized air pollution through (1) targeted incentive funding to deploy cleaner technologies and (2) grants to support community participation in the Assembly Bill 617 (AB 617) process.[77]	• Report criteria and toxic emissions data annually using a uniform statewide system. • Collect emissions inventory data, which helps to guide and provide the scientific basis for CARB's regulatory development process, to identify and address areas of concern, and to track progress in emission reduction efforts from stationary, mobile, and area sources.

The above policies have included public health as a goal. For example, the *Regulation for the Reporting of Criteria Air Pollutants and Toxic Air Contaminants* implements statewide annual reporting of criteria air pollutant and toxic air emissions data. The regulation states that this reporting is required since these pollutants "may contribute to adverse health risks."[78] Under the regulation, "elevated toxics facilities," which are those categorized by the local air district as a high priority for toxic air contaminant emissions based on cancer or noncancer health impacts, must submit emissions reports to CARB for criteria air pollutants and toxic air contaminants.[79]

The *Community Air Protection Program* implements Assembly Bill 617, which requires new community-focused actions to reduce air pollution and improve public health in communities that experience disproportionate burdens from air pollutants exposure.[80] The program focuses on monitoring community air quality while also implementing community emissions reduction programs. Particularly, community emissions reduction programs are designed to focus on health-based air quality objectives. The blueprint for the program states that such objectives "can include reducing

75 Senate Bill 1382 (2022).

76 California Air Resources Board (2018a, 2020).

77 The AB 617 process requires retrofitting of industrial sources, increased penalty fees, and greater transparency and availability of air quality and emissions data, which will help advance air pollution control efforts throughout the State. Communities slated for participation in the AB 617 process are those identified as being overburdened by air pollution, as identified by the State and Air Districts (Assembly Bill 617, 2017).

78 California Air Resources Board (2020).

79 Cornell Law School (2020).

80 California Air Resources Board (2018a).

levels of fine particles to improve health outcomes and maximizing progress in reducing exposure to air toxics such as diesel exhaust, benzene, toxic metals, and others." The community monitoring program also has a public health focus, as it may generate data to support public health notification systems and public health research.[81] An example of the *Community Air Protection Program* is the air pollution abatement program and planning that the Bay Area Air Quality Management District has been conducting in several Bay Area communities, such as the West Oakland Community.[82]

Measurement of Public Health Impact

CARB also has air quality policies and programs to measure the impacts of air pollution on public health, particularly in areas with higher air pollution or with regard to more vulnerable populations. These policies and programs are summarized in Table 3.

TABLE 3 | Summary of California's Air Quality Policies Measuring the Public Health Impacts of Air Pollution

Policy	**Air Toxics "Hot Spots" Information and Assessment Act (Assembly Bill 2588)[83]**	**Children's Environmental Health Protection Program (Senate Bill 25)[84]**
Year Enacted	1987	1999
Main Goals	• Require reporting of air releases for stationary sources.	• Examine the impacts of air pollution on children's health.
Main Tasks	• Collect emission data. • Identify facilities having localized impacts. • Ascertain health risks. • Notify nearby residents of significant risks. • Reduce the above significant risks to acceptable levels.	• Conduct special studies to determine whether the current air quality measurement network adequately reflects the levels of air pollutants that infants and children are breathing. • Expand CARB's existing monitoring program in six communities around the state and conduct special monitoring at locations where children are typically present and near sources of air pollution.

Both the *Air Toxics "Hot Spots" Information and Assessment Act* and the *Children's Environmental Health Protection Program* measure the public health impacts of air pollution. For example, the *Air Toxics "Hot Spots" Information and Assessment Act* requires high-priority facilities[85] to submit health risk assessments. These health risk assessments are reviewed by the Office of Environmental Health Hazard Assessment (OEHHA) and approved by the relevant air quality management district. In these health risk assessments, hot spots must measure the cancer risks from exposure to facility emissions, as well as non-cancer risk assessments in line with acute, 8-hour, and chronic exposure levels of selected pollutants.[86] OEHHA provides a comprehensive summary of the target organs (i.e., respiratory, eyes, cardiovascular, immune system) to be assessed given the exposure to various substances.[87]

The *Children's Environmental Health Protection Program* establishes specific requirements to examine the impacts of air pollution on children's health.[88] This is because "[a]ir pollution is

81 California Air Resources Board (2018b).

82 MacIver (2021).

83 California Air Resources Board (n.d.-c).

84 California Air Resources Board (n.d.-d).

85 High-priority facilities are determined by a "prioritization score threshold" set by each air quality district, which considers a set of indicators related to hazardous materials that may pose a "significant risk." California Air Resources Board (n.d.-e).

86 California Air Resources Board (n.d.-f).

87 OEHHA (2022).

88 California Air Resources Board (n.d.-g).

known to exacerbate asthma and be a trigger for asthma attacks in infants and children, 500,000 of whom are afflicted with this chronic lung disease in California."[89] In addition to expanding California's air quality monitoring program and conducting special monitoring at locations where children are typically present, the program also requires CARB and the OEHHA to consider the health impacts of subpopulations of infants and children, such as "children with asthma, cystic fibrosis, or other respiratory conditions or diseases."[90]

Besides those two policies mentioned above, CARB also has established a methodology for estimating the health effects related to $PM_{2.5}$ exposure.[91] Relevant public health indicators include premature death from cardiopulmonary causes, hospitalizations for cardiovascular and respiratory causes, and emergency room visits for asthma.[92] This focus on the health impacts of air pollution signals that CARB is concerned with the public health implications of air quality in California.

Finally, beyond CARB, OEHHA has also developed CalEnviroScreen, a mapping tool that helps identify which Californian communities are most affected by air pollution. Scores for every census tract in the state are based on environmental, public health, and socioeconomic information. CalEnviroScreen enables policymakers to visualize health inequities and other population-level health issues, which can then be incorporated into air quality and climate change policies.[93]

California's Climate Policies

Over the last two decades, California has set forth a legislative climate agenda that reflects the increasing predominance of health considerations in climate policymaking. Among these include the *Global Warming Solutions Act* (Assembly Bill 32) and its 2016 successor, *California Global Warming Solutions Act: emissions limit* (Senate Bill 32); the *Renewable Portfolio Standard*; and policies on short-lived climate pollutants, among others. California's climate policies recognize that climate change could exacerbate both public health and air quality problems. The *Global Warming Solutions Act* declares in its very first section that global warming poses a serious threat to public health, and that "[t]he potential adverse impacts of global warming include the exacerbation of air quality problems."[94] The *Short-Lived Climate Pollutant Strategy* also declares that "[s]hort-lived climate pollutants, such as black carbon, fluorinated gases, and methane, are powerful climate forcers that have a dramatic and detrimental effect on air quality, public health, and climate change."[95] This section details California's policy portfolio, which includes public health among its motivations.

Framework Climate Change Legislation: The Global Warming Solutions Act

California's seminal climate change mitigation legislation is Assembly Bill 32 (*Global Warming Solutions Act*), which sets a target for mitigating GHG emissions by 2020. Following the passage of the act, California gradually established a climate policy framework, which includes various GHG emission reduction measures, such as the *Low Carbon Fuel Standard,* which decreases transportation emissions,[96] and the Cap-and-Trade program for major sources of GHG emissions.[97] The *Global Warming Solutions Act* was then updated in 2016 under Senate Bill 32 to make California's GHG reduction targets more stringent. Table 4 summarizes this legislation.

California's *Global Warming Solutions Act* is, in part, motivated by the public health impacts of climate change. For example, the act declares that global warming "poses a serious threat

89 Senate Bill 25 (1999).

90 Senate Bill 25 (1999).

91 California Air Resources Board (n.d.-h).

92 California Air Resources Board (n.d.-i).

93 Ganesh & Smith (2018).

94 Global Warming Solutions Act (2006).

95 Senate Bill 1383 (2016).

96 California Air Resources Board (n.d.-j).

97 California Air Resources Board (n.d.-k).

to the … public health … of California," and that potential adverse impacts include "an increase in the incidences of infectious diseases, asthma, and other human health-related problems."[98] The updated 2016 *Global Warming Solutions Act* augmented this public health focus with an environmental justice angle. Specifically, the 2016 act highlighted that it was critical to continue reducing GHG emissions because California's "most disadvantaged communities are disproportionately impacted by the deleterious effects of climate change on public health."[99]

TABLE 4 | Summary of the Global Warming Solutions Act 2006 (AB 32) and SB 32

Policy	Global Warming Solutions Act (AB 32)[100]	Global Warming Solutions Act: emissions limit (SB 32)[101]
Year Enacted	**2006**	**2016**
Main Goals	• Reduce GHG emissions to 1990 levels by 2020, which is estimated to be a 30% reduction.	• Reduce GHG emissions to 40% below the 1990 level by 2030.
Main Tasks	• Develop and update a Scoping Plan every five years for cost-effective GHG emission reductions. • Maintain and continue reductions in emissions of GHGs beyond 2020. • Establish regulations for early actions by January 1, 2010, and market-based emission limits. • Convene an Environmental Justice Advisory Committee and an Economic and Technology Advancement Advisory Committee for input and recommendations.	• Develop and update a Scoping Plan every five years for cost-effective GHG emission reductions. • CARB must reach the above goal in a manner that benefits the state's most disadvantaged communities and is transparent and accountable to the public and the Legislature.

The *Global Warming Solutions Act* further takes into account the public health benefits of its GHG emission reduction measures. For example, the 2006 act provides that CARB's GHG emission limits and reduction measures shall consider "overall societal benefits," including "benefits to … public health."[102] CARB thus must prepare scoping plans to implement GHG emissions reduction, under which CARB must evaluate "the total potential costs and total potential economic and noneconomic benefits … to [California's] public health."[103]

Addressing recent legislation and guidance from Governor Newsom, CARB's *2022 Scoping Plan* furthers earlier plans by aiming to reduce anthropogenic emissions to 85 percent below 1990 levels by 2045. While broadly focused on increasing the decarbonization of sectors that produce GHGs, such as transportation, this plan also explicitly evaluates the direct health benefits of the successful implementation of CARB's Scoping Plan. Additional details on the public health assessment measures contained within the Scoping Plan are included in Annexes I and II of this report.

Other Climate Change Mitigation Policies

Beyond the The *Global Warming Solutions Act*, some of California's climate change mitigation policies—which were enacted to achieve GHG emission reduction targets set forth under the *Global Warming Solutions Act*—also explicitly seek to advance public health. One example is California's prohibition of certain hydrofluorocarbons. Under the regulation, variances to the prohibition may be issued only if an exemption from the regulations will not increase the overall risk to human

98 Global Warming Solutions Act (2006).
99 Senate Bill 25 (1999).
100 California Air Resources Board (2018c).
101 Senate Bill 32 (2016).
102 Global Warming Solutions Act (2006).
103 Global Warming Solutions Act (2006).

health or the environment.[104] Applications for variances from CARB's regulatory requirements must also include a description of and mitigation plan for any negative impacts to human health that may result.[105] California has additional climate policies that are motivated by public health. Table 5 summarizes several such policies.

TABLE 5 | Summary of Some Other Climate Policies Motivated by Public Health

Policy	Year	Main Goals	Measures
Short-Lived Climate Pollutant (SLCP) Strategy[106]	**2016**	• Develop and implement a comprehensive SLCP reduction strategy. • Mitigate the effect of SLCP on air quality, public health, and climate change.	• Target reductions in methane (40%), HFCs (40%), and anthropogenic black carbon (50%) below 2013 levels by 2030. • Implement regulations to reduce methane emissions from dairy and livestock manure management operations. • Mandate a 50% reduction in statewide organic waste disposal by 2020; 75% reduction by 2025 • Reduce fugitive methane emissions from oil and gas (40% below current levels by 2025) and other sources (40% reduction by 2030).
California Renewables Portfolio Standard[107]	**2018**	• California Public Utilities Commission (PUC) to achieve its 50% renewable resources target by 31 December 2026, and a 60% target by 31 December 2030.	• Mandate retailers and electric utilities to increase renewable energy sourcing: 44% by 2024, 52% by 2027, and 60% by 2030. • Establish a goal for a 100% renewable and zero-carbon energy supply to California customers and state agencies by 2045, without increasing emissions in the western grid.
California Climate Crisis Act[108]	**2022**	• Achieve net zero GHG emissions as soon as possible, but no later than 2045. • By 2045, GHGs will be reduced to at least 85% below 1990 levels.	• Require CARB to work with relevant state agencies to enable carbon dioxide removal solutions and carbon capture, utilization, and storage technologies in California.
Senate Bill 375[109]	**2008**	• Set regional targets for GHG emission reductions from vehicles. • Support California's climate goals and improve public health through sustainable transportation, housing, and land-use planning.	• Improve regional transportation patterns through the regional transportation plan. • Link land-use, housing, and transportation planning, and incorporate public health components in the planning.

Of the policies mentioned above, the *Short-Lived Climate Pollutant Strategy and the Air Cleaner Regulation* are explicitly motivated by public health. The *Short-Lived Climate Pollutant Strategy* declares that short-lived climate pollutants "such as black carbon, fluorinated gases, and methane, are powerful climate forcers that have a dramatic and detrimental effect on ...

104 Cornell Law School (2020).

105 Cornell Law School (2020).

106 California Air Resources Board (n.d.-l).

107 California Public Utilities Commission (n.d.).

108 Assembly Bill 1279 (2022).

109 Senate Bill 375 (2008).

public health," and "are a significant environmental risk factor for premature death."[110] It further declares that reducing the emission of these pollutants "can have an immediate beneficial impact on climate change and on public health."[111] This public health focus is reinforced in the implementation of the strategy, since CARB must "[i]ncorporate and prioritize, as appropriate, measures and actions" that provide public health co-benefits.[112] Some of these measures include the use of ultra-low-NO_x vehicles and renewable natural gas in transportation, diverting organics from landfills to compost facilities and anaerobic digestion facilities, and converting dairies from flush water manure management systems to dry manure management systems.[113]

The California *Renewables Portfolio Standard* also seeks to improve public health in California.[114] By diversifying California's sustainable energy generation portfolio, California can reduce GHG emissions, reduce air pollution, and stabilize electric retail rates, thus relieving the public health burden throughout the state.

The California *Climate Crisis Act*, however, is not explicitly motivated by public health. Though it declares that "[m]illions of Californians breathe unhealthy air," it stops short of mentioning the health co-benefits of the act.[115] However, it may be implied that the act is motivated by public health given that it seeks to implement the California Global Warming Solutions Act, which does set public health as an explicit goal.

Worth noting that not all climate policies have public health as a main motivation. The *Climate Heat Impact Response Program*, for instance, is targeted at improving grid resilience during extreme heat events but has public health as a secondary motivation. The program seeks to mitigate emission increases from the power system during extreme heat events and minimize the public health impacts that may follow when electricity grids fail during such extreme events.[116] Additionally, the *Low Carbon Fuel Standard* under the *Global Warming Solutions Act* considers the public health benefits in its reform of the transportation sector, albeit to a small extent. For instance, equity projects to support transportation electrification under the *Low Carbon Fuel Standard* may include multilingual marketing, education, and outreach to increase information sharing about the environmental, economic, and health benefits of electric vehicle transportation.[117]

Conclusion

Despite having a robust portfolio of policy actions that include public health considerations in California, some policies simply stop at declaring that public health benefits or costs are associated with air pollution and climate change mitigation, and do not elaborate. Additionally, public health indicators for each policy often differ, making it difficult to compare the public health effectiveness across policies. For instance, while the California SIP acknowledges that there are public health impacts resulting from poor air quality, and sets health-based standards for air quality, the SIP does not establish uniform health indicators to measure the effectiveness of its policies.

Major California policies and programs integrate the three pillars of public health, air quality, and climate change, either by taking into account GHG emission reduction when tackling air quality or by recognizing that climate change will impact air quality. The recognition of this synergy between public health, air quality, and climate change may be rooted in the way in which CARB is California's lead agency for both air pollution control and climate change programs.[118]

110 Senate Bill 1383 (2016).
111 Senate Bill 1383 (2016).
112 Senate Bill 1383 (2016).
113 California Air Resources Board (2017).
114 Senate Bill 100 (2018).
115 Assembly Bill 1279 (2022).
116 California Air Resources Board (2021).
117 Cornell Law School (2020).
118 Balmes (2021).

3.2 China's Approaches

In recent years, China has adopted a series of policies to improve air quality and reduce carbon emissions, and has simultaneously achieved significant progress. According to a report released by the Chinese MEE in 2022, the national average $PM_{2.5}$ concentration dropped from 72 $\mu g/m^3$ to 30 $\mu g/m^3$ between 2013 and 2021, resulting in significant health co-benefits.[119] Meanwhile, by 2020, China's carbon intensity has decreased by 18.8% compared to 2015 levels, and energy intensity has dropped by 28.7% between 2011 and 2020.[120]

This section briefly summarizes China's policies for air pollution control and climate change mitigation and discusses the interconnection between air, climate, and public health in China's policies.

China's Air Pollution Control Policy

China has taken stringent policies to combat air pollution challenges to protect public health. The two most important laws related to air pollution control are the *Environmental Protection Law* and the *Atmospheric Pollution Prevention and Control Law*. Both laws have placed emphasis on the public health impacts of air pollution and set the protection of public health as one of their primary goals. Specifically, the *Environmental Protection Law* emphasizes "safeguarding the health of the general public" and mentions that "[t]he state should establish and improve the environment and health monitoring, investigation and risk assessment system..., and encourage research on the environment's impact on public health."[121] The *Atmospheric Pollution Prevention and Control Law* also sets "safeguarding the health of the general public" as a major goal, and mentions that "ambient air quality standard should be formulated for the purpose of protecting public health."[122]

Besides legislation, China revised its ambient air quality standards in 2012 and added standards for $PM_{2.5}$ and 8-hour average ozone concentrations, meaning that China took further steps in mitigating air pollution.[123] In addition, China has also adopted a series of policies to control air pollution, and most of those policies set public health protection as one of their motivations. Table 6 below provides a brief summary of four major air pollution control policies in China in the past decade.[124] In 2019, China also published the Technical specifications for health risk assessment of ambient air pollution, which provides standard processes and evaluation tools for estimating the public health risk of air pollution.[125]

Some policies reflect the synergies between air pollution control and climate change mitigation. Phrases such as "control coal consumption and combustion emission," "regulate industries with high energy consumption and high pollution," "increase energy efficiency," and "develop clean energy" are included in the tasks of many policies. Specifically, one of the main goals of the *Three-Year Action Plan for Winning the Blue Sky Defense Battle* is to "simultaneously reduce GHG emissions while controlling air pollution."[126] Similarly, *The Opinions on Winning the Battle of Preventing and Controlling Environmental Pollution* emphasizes that the "synergy between pollution reduction and carbon mitigation" should be a guiding principle of policy implementation, and sets the target of CO_2 emission per 10,000 yuan of GDP for 2020.[127]

119 Ministry of Ecology and Environment (2014, 2022a); W. Xue et al. (2021).

120 China's State Council (2021a).

121 Environmental Protection Law of the People's Republic of China (2014).

122 Atmospheric Pollution Prevention and Control Law of the People's Republic of China (2015 Revision) (2018).

123 X. Guo (2019).

124 Central Committee of the Chinese Communist Party & State's Council (2021a); China's State Council (2010a, 2013a, 2018a).

125 National Health Commission of the People's Republic of China (2019).

126 China's State Council (2018a).

127 Central Committee of the Chinese Communist Party & State's Council (2021b).

TABLE 6 | Summary of Four Major Air Pollution Control Policies in China[128]

Policy	Year	Covered Areas	Main Goals	Measures
Joint Prevention and Control of Air Pollution	**2010**	• Regional air pollution issues such as acid rain, smog, and photochemical smog	• Establish a cooperative prevention and control system for regional air pollution by 2015. • Reduce air pollutant emissions. • Reduce the cases of acid rain, smog, and photochemical smog. • Ensure good air quality for the Shanghai EXPO 2010 and Guangzhou 2010 Asian Games.	• Conduct regional air pollution prevention and control in three key areas and six city clusters. • Control key air pollutants, including SO_2, NO_x, $PM_{2.5}$, and VOCs. • Regulate certain industries, such as thermal power, iron and steel, non-ferrous metals, petrochemicals, cement, and chemicals.
Action Plan on Air Pollution Prevention and Control (2013–2017)	**2013**	• Regional air pollutants such as $PM_{2.5}$ and PM_{10}	• Annual PM_{10} levels to be decreased by at least 10% compared with 2012 levels in urban areas and "blue sky" days to be increased year by year. • Annual $PM_{2.5}$ concentrations to be reduced by at least 25%, 20%, and 15% in the Beijing-Tianjin-Hebei, Yangtze River Delta, and Pearl River Delta region, respectively.	• Control nonpoint source and mobile source pollution control; implement regional air pollution control. • Regulate industries, with "high energy consumption and high pollution," such as thermal power, iron and steel, non-ferrous metals, petrochemicals, cement, and chemicals. • Encourage technology innovation. • Foster research on the relationship between air pollution and public health. • Adjust energy structure by controlling coal consumption and encouraging the use of clean energy.
Three-Year Action Plan for Winning the Blue Sky Defense Battle	**2018**	• Regional air pollutants such as $PM_{2.5}$ • Synergy between air pollution control and climate change mitigation • Air quality goals in the 13th Five-Year Plan	• By 2020, SO_2 and NO_x emissions to be reduced by at least 15% compared with 2015 levels. • The percentage of "blue sky days" should be at least 80% by 2020.	• Adjust the industry structure by relocating polluting industries and regulating industries with "high energy consumption and high pollution." • Adjust the energy structure by controlling coal consumption, encouraging the use of clean energy, and increasing energy efficiency. • Develop green transportation. • Conduct specific actions for fall and winter air pollution, VOCs, diesel trucks, etc. • Control regional air pollution.
The Opinions on Winning the Battle of Preventing and Controlling Environmental Pollution	**2021**	• Regional air pollutants such as $PM_{2.5}$ • Synergy between air pollution control and climate mitigation • Setting goals for the 14th Five-Year Plan	• $PM_{2.5}$ concentrations to be decreased by at least 10% by 2025. • Percentage of "blue sky days" should be at least 87.5% by 2025.	• Promote low-carbon economy. • Promote clean energy. • Reduce air pollution levels during fall and winter. • Reduce ozone concentrations in summer. • Reduce air pollutants emissions from nonpoint sources.

128 Central Committee of the Chinese Communist Party & State's Council (2021a); China's State Council (2010b, 2013b, 2018b).

For public health issues in air pollution control policies, the research on air pollution impacts on public health and impact prevention is mentioned explicitly as one strategy to strengthen the scientific foundation for air pollution control in the *Three-Year Action Plan for Winning the Blue Sky Defense Battle*.[129] The implementation of this strategy has been effective, as China has consistently monitored the public health impacts of air pollution and has installed 167 monitoring stations in 87 cities across 31 provinces.[130] Other actions related to public health are barely mentioned in the air pollution control policies above.

There are some overlaps between China's air pollution control policies and its public health policies. The Communist Party of China's Central Committee and the State Council released the *Healthy China 2030* plan in 2016, requiring that the mechanism of joint prevention and control of air pollution should be fully implemented, and the air quality in cities should "improve significantly." Specifically, the plan requires the proportion of days with good air quality in cities to exceed 80%.[131] In 2019, China's State Council released the *Healthy China Action Plan*, aiming to further improve the assessment of public health impacts of air pollution.[132] China's latest 14th Five-Year Plan (FYP) for people's health requires northern cities in China to substitute coal with clean energy for winter heating and set "eliminating heavily polluted days" as a target. Both requirements, closely related to air pollution control, are important measures to "strengthen environmental health management."[133] These overlapping policies are likely to result in a synergy between air pollution control and public health improvement, showing that China is taking action to achieve the public health co-benefits of air pollution control. However, not all public health policies include air pollution issues. For example, air pollution and health considerations were absent from the 14th Five-Year Plan for Healthy Aging, reflecting a lack of understanding of the impacts of air pollution on the vulnerable group of the elderly.[134]

China's Climate Mitigation and Adaptation Policy

Since China declared its 2030 carbon peaking and 2060 carbon neutrality goals in 2020, climate mitigation has been an important component of its national strategy. To achieve these ambitious goals, China designed a policy scheme for carbon peaking and carbon neutrality and took a step further in implementing climate adaptation strategies.

One of the most important breakthroughs in China's climate mitigation action is constructing the "1+N" climate mitigation policy scheme. In its 14th Five-Year Plan, China set "reducing CO_2 emissions per 10,000 yuan of GDP by 18% in 2025 compared with 2020" as a binding target. To fulfill this goal, a series of policies have been released at the national, provincial, and city levels, forming a comprehensive policy scheme called the "1+N" scheme. Inside the "1+N," the "1" represents two leading climate policy documents in China, which are the guiding ideology and top-level design for carbon peaking and carbon neutrality, and the "N" refers to implementation plans in key areas and key industries, as well as supporting plans. In other words, "1" defines the schedule and roadmap for China to achieve its ambitious goals, while "N" defines implementation plans for different industries in more detail. Analyzing the "1" (Table 7) will help depict the relationship between climate mitigation, air pollution control, and public health improvement.

Similar to the major air pollution control policies mentioned before, China's two leading climate policies incorporate the synergies between air pollution control and climate mitigation. In the *Working Guidance for Carbon Dioxide Peaking and Carbon Neutrality in Full and Faithful Implementation of the New Development Philosophy* (hereafter "Working Guidance"), concepts

129 China's State Council (2018a).

130 Ministry of Ecology and Environment (2022b).

131 Central Committee of the Chinese Communist Party & State's Council (2016).

132 Healthy China Action Promotion Committee (2019).

133 China's State Council (2022).

134 China's National Health Commission (2022).

such as “regulate industries with high energy consumption and high pollution,” “strictly control fossil fuel consumption,” and “promote low-emission vehicles” were emphasized, demonstrating China’s commitment to addressing air pollution and climate challenges together.[135]

TABLE 7 | Summary of the Two Leading Climate Policy Documents (the “1”)[136]

Policy	Working Guidance for Carbon Dioxide Peaking and Carbon Neutrality in Full and Faithful Implementation of the New Development Philosophy	Action Plan for Carbon Dioxide Peaking before 2030
Year Published	**2021**	**2021**
Main Goals	• By 2025, circular economic systems should be established; energy efficiency in key industries increases. • By 2030, economic and social development has achieved significant success in a comprehensive green transformation, with energy efficiency in key energy-consuming industries reaching international advanced levels. • By 2060, the circular economy system and clean energy system should be fully established; the proportion of non-fossil energy consumption reaches about 80%; achieve carbon neutrality.	• By 2025, energy consumption per 10,000 yuan of GDP drops by 13.5%;[137] CO_2 emission per 10,000 yuan of GDP drops by 18%;[138] the proportion of non-fossil energy consumption reaches about 20%. • By 2030, CO_2 emissions per 10,000 yuan of GDP drops by 65%;[139] the proportion of non-fossil energy consumption reaches about 25%; achieve carbon peaking.
Main Tasks	• Promote low-carbon economic development and adjust the industrial structure. • Establish a clean, low-carbon, and secure energy system. • Develop a low-carbon transportation system and promote sustainable urban planning. • Foster green technology innovation, enhance carbon sink capacity, and improve regulations and monitoring systems.	• Establish clean, secure, and low-carbon energy systems. • Focus on energy efficiency and carbon emission reduction. • Achieve carbon peaking in key industries and promote sustainable urban planning. • Reduce emissions from transportation, promote a circular economy, support green technology innovation, enhance carbon sequestration capacity, and encourage low-carbon lifestyles.

However, although China’s guiding climate policies reflect the synergies between air and climate, the relationship between climate change mitigation and public health improvement is rarely mentioned. The main goals of those two policies focus on carbon intensity, energy intensity, and the proportion of non-fossil fuel consumption. Public health is not part of the policy efficiency indicators of China’s climate policies.

Despite a lack of public health components in China’s guiding climate change and carbon neutrality policies, China did mention public health explicitly in its national climate adaptation strategy. There have been two national climate adaptation strategies in China, published in 2013 and 2022. Both strategies established public health adaptation as an important priority, while the 2022 edition provided more detail regarding the specific adaptation actions. These strategies, especially the newer one, will help strengthen the analysis and assessment of the

135 Central Committee of the Chinese Communist Party & State’s Council (2021b).

136 Central Committee of the Chinese Communist Party & State’s Council (2021b); China’s State Council (2021b).

137 Compared to 2020 levels.

138 Compared to 2020 levels.

139 Compared to 2005 levels.

public health impacts and risks of climate change and enhance improvements in the public health system. Table 8 summarizes the major tasks in these strategies.

TABLE 8 | Summary of the Major Tasks in China's National Climate Adaptation Strategies[140]

Strategy		National Climate Adaptation Strategy	National Climate Adaptation Strategy 2035
Published Year		2013	2022
Main Tasks	Climate impact assessment	• Conduct assessments of climate change health risks and adaptive capacity, and identify vulnerable groups.	• Conduct assessments of climate change health risks and adaptive capacity, and identify vulnerable groups.
	Control climate-related diseases	• Enhance the overall health and epidemic prevention infrastructure by reinforcing disease prevention and control, health education, health supervision, law enforcement, and public health service capacities.	• Strengthen the monitoring, early warning, prevention, and control of climate-sensitive diseases, and formulate climate change health adaptation action plans.
	Strengthen public health system resilience	• Enhance emergency system construction, including health emergency preparedness and the development of plans for extreme weather and climate-related health emergencies.	• Strengthen the climate resilience of the health care system and conduct special research on health adaptation.
	Conduct pilot projects	• Conduct pilot monitoring projects for epidemic control and enhance emergency reaction systems for heat waves.	• Conduct pilot projects of adaptation in cities, villages, communities, and key places (schools, hospitals, elderly care institutions, etc.) to improve the level of public health adaptation to climate change and extreme weather events.

Under these adaptation strategies, several public health programs have been or will be implemented. According to the National Climate Adaptation Strategy in 2013, a pilot project was conducted in Chongqing, a midwest city in China, to address heat waves and climate-sensitive diseases, with a focus on controlling epidemics, building extreme weather forecasting systems, and establishing public health monitoring networks.[141] By 2020, emergency plans for different disasters such as floods and typhoons have been formulated, health impact assessments of extreme weather and climate change adaptation studies have been carried out, and early warning systems for climate-sensitive diseases have been established in some cities.[142] In 2020, China has also organized research on the impact of extreme weather on public health as well as the impact of climate change on the spread of parasitic diseases, and conducted special surveys on meteorologically sensitive diseases.[143] In addition, China is now drafting a standard guideline on vulnerability, impacts, and risk assessment for climate change, based on the international standard ISO 14091:2021.[144] Last but not least, according to China's National Climate Adaptation Strategy, some special actions are to be implemented in the coming decades, with plans for 2025 and 2035 set.[145]

140 Ministry of Ecology and Environment (2022c); National Development and Reform Commission (2013a).

141 National Development and Reform Commission (2013b).

142 Huang (2022).

143 Ministry of Ecology and Environment (2022b).

144 China National Institute of Standardization (2022).

145 Ministry of Ecology and Environment (2022b).

These actions include: conducting special research on health adaptation to climate change; developing assessment guidelines, standards, and adaptation implementation plans for the health impacts of climate change and extreme climate events; and demonstrating health adaptation to climate change and extreme climate events through pilot projects (Table 9).

TABLE 9 | Special Actions for Public Health Adaptation to Climate Change[146]

Special Action Types	Actions by 2025	Actions by 2035
Conducting special research on public health adaptation	• Carry out health impact research for climate change and extreme weather, and clarify the main health risks. • Depict characteristics of vulnerable areas and populations.	• Carry out research on adaptation strategies and technologies for climate change and extreme weather. • Complete adaptation strategies, technologies, and programs.
Developing assessment guidelines, standards, and adaptation plans for public health impacts of climate change and extreme climate events	• Complete climate health risk assessment guidelines and assessment standards. • Formulate public health adaptation plans to climate change and extreme climate events.	• Complete climate health risk assessment guidelines and assessment standards for different regions in China. • Formulate public health adaptation plans to climate change and extreme climate events for different regions in China.
Demonstrating public health adaptation to climate change and extreme climate events through pilot projects	• Based on factors such as climate, ecological environment, and population characteristics in different regions, conduct public health adaptation pilot projects for climate change and extreme climate events. • Compile health and nutrition guidelines for populations facing climate health risk.	• Promote nationwide adaptation action to climate change and extreme weather. • Significantly improve the ability to adapt to climate change in different regions in China.

In summary, China's current climate-related public health strategies focus on adaptation to extreme weather and climate-sensitive diseases. However, there is no stand-alone national health adaptation plan in China to date. The latest national adaptation strategies reflect that China's public health adaptation to climate change is still in its nascency, and there are limited climate change health risk assessment guidelines or standards in China.[147] There is also a lack of quantitative targets for public health benefits in those adaptation strategies.

Climate change considerations are not well incorporated into China's latest public health policies. There is much less overlap between China's climate change mitigation and public health policies than between air pollution and public health policies, as was mentioned before. The Healthy China Action Promotion Committee added "promoting actions to address health impacts of climate change" in the annual working priorities of the *Healthy China Action Plan* for the first time in 2022.[148] However, other public health policies, such as *Healthy China 2030*, the 14th Five-Year Plan (FYP) for people's health, and the 14th Five-Year Plan (FYP) for Healthy Aging, do not have climate-related content. This omission exposes a concerning lack of understanding within the health sector, government, and public that climate change is becoming the defining factor of China's public health profile and has already affected China's public health situation.[149]

146 Ministry of Ecology and Environment (2022c).

147 W. Ma et al. (2018).

148 Healthy China Action Promotion Committee (2022).

149 W. Ma et al. (2018).

China's Subnational Policy

Since 2022, many provinces have published their 14th FYPs for environmental protection and climate change mitigation, which cover a broad range of air pollution and climate issues, such as industry structure adjustment, GHG emission abatement, climate adaptation, and environmental health risk surveillance.[150] In most provincial FYPs, public health improvement is regarded as an important motivation to control air pollution, and public health risk prevention is a main goal and guiding principle for air pollution control actions, which is similar to national-level policies. As for content related to climate change, public health issues are mentioned mostly with regard to adaptation. Many provincial FYPs also emphasize the importance of strengthening the assessment of public health impacts of climate change, and they plan to accelerate research on this topic. However, no quantitative goal for public health improvement is set, and most goals and proposed actions are qualitative.

Much progress has been made in the field of public health adaptation to climate change at the subnational level in 2022. Guangdong is the pioneer in health adaptation, as it has conducted a comprehensive assessment of climate change health effects and clinical vulnerability and has established a dengue fever epidemic monitoring system.[151] A few other cities in Jiangsu, Shandong, Xinjiang, and Zhejiang provinces have also conducted climate impact evaluations. Meteorological departments in most provinces have provided meteorological data to the public health sector and have collaborated with public health departments on research.[152] Overall, public health adaptation capacity has improved significantly.

Despite the progress, many provinces in China still lack the plans to address climate-related health risks due to insufficient governmental funding.[153] Moreover, clinically vulnerable groups, such as older populations, are not fully considered in existing adaptation policies, which may negatively affect the efficiency of China's subnational adaptation policies.[154] Therefore, more resources and attention still need to be directed to adaptation efforts. Additionally, public health co-benefits of addressing climate change and air pollution simultaneously should also be emphasized and recognized in policies. Pointed out by research, assessment, and modeling results, quantitative public health goals should be incorporated in future climate and air plans to further benefit populations in China.

Conclusion

Public health protection is an important motivation for China's air pollution control laws and policies. However, China's top-level climate mitigation policies have little focus on public health as a motivating factor. Most targets and tasks in China's climate policies focus on energy efficiency and carbon intensity. The potential public health co-benefits of climate change mitigation is not part of the motivation for making climate policies.

The interconnection between those three pillars—air pollution, climate change, and public health—is not emphasized equally in China's policies. The synergy between air pollution control and climate change mitigation is emphasized in both air and climate policies. There are also many overlaps between air pollution control policies and public health policies. Some phrases used to describe future actions are identical in air and public health policies. This means that China is taking action to achieve the public health co-benefits of air pollution control. On the other hand, there are few overlaps between China's climate change mitigation policies and public health policies. Contents related to public health appear little in the national climate change mitigation policies, and climate considerations

150 Y. Li (2022).

151 Huang (2022).

152 Cai et al. (2022).

153 Cai et al. (2022).

154 Ji et al. (2019).

are almost absent from major public health policies. Even though China's climate change adaptation strategies include public health issues, clinically vulnerable groups, such as older populations, are not fully considered in existing adaptation policies, which might negatively affect the efficiency of China's subnational adaptation policies.

In other words, the co-benefits of addressing air pollution and public health problems together and addressing air and climate problems together are well recognized in China's policies, but the synergy between climate change mitigation and public health improvements is not emphasized enough in current policies, as most climate-related public health policies focus on adaptation. Some places in China, such as the whole province of Guangdong and a few cities in Jiangsu, Shandong, Xinjiang, and Zhejiang provinces, realize this gap. They conduct research to assess the impact of climate change on public health, as well as monitor climate-sensitive diseases, and they have made some progress. However, there is still a lack of comprehensive understanding of the public health impacts of climate change, and there is no standard methodology to estimate or predict the public health co-benefits of climate change mitigation.[155] The result is that no quantifiable targets related to public health are included in China's climate policies.

There are two potential solutions. One is to increase the financial and technical support for more studies on the public health impact of climate change, which should cover a broad range of topics such as health impacts, climate impacts on public health services, and social and economic implications due to health impacts. Such information and knowledge could play a very important role in government decision-making. Another one is to raise the awareness of the public health impacts of climate change in the public and government. China's successful experience in combating air pollution showed that once the problem of air pollution is noticed by the public and government, the government will adopt strategies and policies faster to address the air pollution. This lesson could be applied to address the public health impact of climate change as well.

155 W. Ma et al. (2018).

4. ASSESSMENT OF PUBLIC HEALTH CO-BENEFITS

The use of assessment tools like indicators helps track momentum toward achieving public health targets and enables jurisdictions to assess progress over time, comparing the efficacy of interventions. This section details the key indicators identified within the scientific literature, which we categorized in three main ways: mortality, morbidity, and others. We additionally describe caveats and uncertainties in the literature.

4.1 Review of Key Scientific Indicators

Mortality

Mortality, addressed as both premature death and avoided premature death, is the most common health indicator identified in the scientific literature. While most papers considered all-cause mortality as their indicator, cardiovascular and respiratory-related mortality was also prevalent. Mortality is counted either daily or annually, with one paper quantifying mortality through years of life lost (YLL). YLL accounts for both premature mortality and the age at which the death occurred. Table 10 identifies the mortality indicators in the literature.

TABLE 10 | Mortality Indicators in the Scientific Literature

Mortality Indicator	Specifics	Literature (non-exhaustive)
Mortality/Avoided Premature Deaths	All-cause (annual or daily)	T. Wang et al. (2020) B. Zhao et al. (2019) Jerrett et al. (2005) R. Chen et al. (2019) Kan et al. (2012) Tong et al. (2018) Yan et al. (2022) Xu et al. (2020) T. Wang et al. (2019) Geng et al. (2021) R. Chen et al. (2018) H. Zhao et al. (2019) Q. Zhang et al. (2022) T. Xue et al. (2022) Shang et al. (2013) Tian et al. (2022) Dong et al. (2020) Cai et al. (2021)
	Cardiovascular and/or Respiratory	Rahman et al. (2022) T. Wang et al. (2019) R. Chen et al. (2019) Q. Chen et al. (2021) R. Chen et al. (2018) Q. Zhang et al. (2022) Yang et al. (2015) Shang et al. (2013) Tian et al. (2022)

Morbidity

Morbidity-related indicators (Table 11) found in the literature include emergency department visits, hospitalizations, adverse birth outcomes, and mental health outcomes.

TABLE 11 | Morbidity Indicators in the Scientific Literature

Morbidity Indicator	Specifics	Literature
Emergency Department Visits	All-cause	Adelaine et al. (2017) Malig et al. (2021)
Hospitalizations	Respiratory, cardiovascular, or mental disorders	Malig et al. (2021) Aguilera et al. (2021) Q. Zhang et al. (2022) Liu et al. (2017)
Adverse Birth Outcomes	Low birth weight	Wilhelm et al. (2012) Coker et al. (2016)
Mental Health	All-symptom	Ducy & Stough (2021)
	Depression	T. Xue et al. (2019)

Other Indicators

Other notable indicators are economic, ranging from annual savings/cost of household medical expenditures,[156] work time loss,[157] and labor productivity loss.[158] In a 2022 report, *The Lancet* separates economic indicators into two groups: the human capital approach and the welfare loss approach.[159] The former uses output lost when a person prematurely dies as an indicator, while the latter uses the value of statistical life, which is used extensively throughout the literature.[160]

The literature also contained environmental justice indicators, including household fuel consumption, home address or zip code, median income, and racial percentages.[161] Several California-focused papers used OEHHA's CalEnviroScreen, which combines multiple indicators.[162] The tool utilizes census data to map environmental, socioeconomic, and health information to rank California communities' vulnerability. CalEnviroScreen's indicators fall into four broad groups: *exposure, environmental effects, sensitive populations,* and *socioeconomic factors*. Direct health indicators, which fall under the "sensitive populations" category, include asthma, cardiovascular diseases, and low birth weight infants. Rates of asthma and cardiovascular diseases are measured through prevalence, emergency department visits, and deaths. Pregnancy outcomes and term low birth weight (TLBW) are measured as the percentage of low-weight births over a set period.

156 T. Xue et al. (2021) and Williams & Phaneuf (2019).

157 Xie et al. (2020).

158 Cai et al. (2021).

159 Fuller et al. (2022, p. 2).

160 Bollen et al. (2009); Cai et al. (2021); Garcia-Menendez et al. (2015); Markandya et al. (2018); West et al. (2013); Yan et al. (2022).

161 Coker et al. (2016); Jerrett et al. (2005), p. 200; B. Zhao et al. (2019).

162 Anderson et al. (2018); Fournier et al. (2022); Mendez (2015).

4.2 Caveats and Uncertainty

While expansive, the indicators found in the literature review are not comprehensive, nor infallible. Measurement of these indicators varies, and the total incidence of disease may not be accurately captured by these metrics. For example, mortality related to cardiovascular and respiratory outcomes is not always accurately reported, which can lead to inaccurate health disparity tracking.[163] There is also uncertainty in the direct association between air pollutants and health outcomes, with certain indicators potentially influenced by confounders. While uncertainty remains within these indicators, the scientific literature and California policy alike use the above mortality and morbidity indicators as some of the strongest measures for health outcomes currently available.

163 McGivern et al. (2017).

5. TECHNOLOGICAL OPPORTUNITIES TO ENHANCE PUBLIC HEALTH CO-BENEFITS

Technology assists stakeholders in addressing air quality and climate change through tools that enable scientists and policymakers to assess air pollution levels, track emission sources, and measure climate change and disease indicators with greater accuracy and granularity. Current technologies include sophisticated computer models and simulations that leverage computational power to analyze and predict air quality patterns, simulate climate scenarios, and explore the impacts of various mitigation strategies. Additionally, data visualization platforms and interactive mapping applications help communicate this information effectively to stakeholders, facilitating informed decision-making and fostering public engagement. Throughout the course of our research, we uncovered several existing technological tools that can help with assessments of public health co-benefits of air quality and climate actions. These include mapping tools and early warning systems, personal and commercial air quality monitoring, data analytics, and digital technologies, among others. A few of these are summarized as follows:

Satellites, Mapping Tools, and Early Warning Systems

Perhaps the most prominently cited mapping tool used regularly in the California context was the federal tool, the EPA's Environmental Benefits Mapping and Analysis (BenMAP). Meanwhile, for vulnerability assessments in California, OEHHA's CalEnviroScreen also proved valuable. In the academic literature, one study points to the importance of disease early warning systems as a consumer tool to help with personal disease prevention.[164] The City of Los Angeles (LA) is using an asthma tracking technology, SmartAirLA[165] to help monitor asthma cases throughout the city and reduce pollution incidence and resulting hospitalizations.

In the Chinese context, the China Meteorological Administration has established the biggest meteorological monitoring system in the world. It consists of 7 in-orbit weather meteorological satellites, 120 high-altitude meteorological observation stations, more than 60,000 national and provincial meteorological observation stations, 89 wind profile radars, 242 new-generation weather radars, and 224 X-band weather radars.[166] This monitoring system not only predicts incoming extreme weather events, but also provides meteorological data that can be utilized to estimate the impact of climate change on weather, air quality, and public health. In addition, to monitor the health impact of climate change and air pollution, the Chinese Center for Disease Control (CDC) established the Chinese Environmental Public Health Tracking System (CEPHT) during the 13th Five-Year Plan period. This system compiles both environment and public health data and supports nationwide climate change and air pollution health impact estimation.[167] In the academic literature, a study details the use of geostationary satellites to provide estimations of hourly ground-level ozone concentrations in China, augmenting ground-level detection methods.[168]

Air Quality Monitoring Tools

Some studies outline how small, portable, monitoring technologies for gaseous pollutants can be utilized as a personal protective measure to help calibrate and reduce personal

164 Ebi & Burton (2008).

165 SmartAirLA (n.d.)

166 Yihong (2023).

167 National Institute of Environmental Health, China CDC (n.d.).

168 Y. Zhang et al. (2023).

exposure to pollutants, thereby potentially yielding health co-benefits.[169] Other studies also outline the role for a regional, distributed, and continuously available sensor network and how they could improve localized air quality monitoring, including accounting for variation in pollutant dispersion across a spatial region.[170] Meanwhile, the relevance of "low-cost" commercial air quality monitoring technologies is also emphasized in some academic literatures.[171]

In the LA context, there are several emerging examples of advances in air quality monitoring, including the following:

1. At the municipal level in LA, there is a predictive air quality monitoring system, supported by the National Aeronautics and Space Administration (NASA), that provides commercial air quality monitoring for the city. Using data from satellites —coupled with local sensors on the ground—data are combined to help show predictive trends in air quality developments.[172] Additionally, the city has a program that enables it to distribute community air purifiers.[173]

2. In addition, as part of the Watts Rising program in LA, the Bureau of Street Lights has installed air quality monitoring to help assess the air quality outcomes of its infrastructure and sanitation investments.[174]

3. Furthermore, the South Coast Air Quality Management District additionally cited the growth in low-cost sensors as an available tool, allowing more coverage and data points within a certain region. SCAQMD performs testing of these sensors and makes the data publicly available on its website Air Quality Sensor Performance Evaluation Center (AQ-SPEC).[175]

In the Chinese context, the government launched the national air quality monitoring system on January 1, 2013. Since then, the China National Environmental Monitoring Center has been publishing real-time air quality data, which consists of the data of $PM_{2.5}$, PM_{10}, NO_2, SO_2, ozone, CO, and air quality index (AQI). Furthermore, Tsinghua University, in collaboration with several institutions including Peking University, Nanjing University, Fudan University, and the Chinese Academy of Meteorological Sciences, has developed and maintained the Tracking Air Pollution in China dataset, aimed at integrating multi-source data such as ground observations, satellite remote sensing, emission inventories, and model simulations. This dataset aims to establish a multi-scale, near-real-time collection of aerosol and gaseous pollutant concentrations in the Chinese atmosphere. It is shared with the scientific community through cloud computing platforms, thereby providing fundamental data support for scientific research related to the health impacts of air pollution, assessments of clean air policies, and environmental management efforts.

Big Data, Artificial Intelligence, and Emerging Digital Technologies

Some academic studies explore the role that advanced technologies like blockchain, the Internet of Things, machine learning, and artificial intelligence may play in overcoming financial and capacity constraints that government agencies can face in addressing air quality and climate issues in tandem. They argue that big data analytics can play a role beyond traditional analyses in making processes more efficient and faster, and enabling a larger scope in shorter time frames while noting certain caveats and limitations of these

169 McKercher et al. (2017); Hubbell et al. (2018); Jerrett et al. (2005).

170 Jiao et al. (2016).

171 Bailey & Solomon (2004).

172 LA City Mayor's Office, personal communication (March 2023).

173 LA City Mayor's Office, personal communication (March 2023).

174 LA City Mayor's Office, personal communication (March 2023).

175 South Coast Air Quality Management District (n.d.-a).

tools.[176] They also point out that, with enhanced storage capabilities, cloud servers enable nearly continuous sensor data collection.[177]

Other studies meanwhile demonstrate the ability of social media combined with machine learning to quickly crowdsource health data in real time, potentially helping to speed the time to identify outbreaks.[178] The use of the Internet of Things in data mapping of pollution sources, as well as for aggregating data, was also explored.[179]

China has been constructing a big data platform for air quality monitoring and health impact analysis. The Chinese government has made substantial enhancements to the scope of its air quality monitoring infrastructure. The count of national monitoring stations in China underwent a notable augmentation, increasing from 496 in 2012 to 1,734 in 2021.[180] This is in addition to monitoring stations overseen and financed by local governmental entities. To better utilize the air quality big data to help enforce air quality policy in China, some pilot projects have been conducted. For example, Cangzhou City launched a platform that takes real-time data from both fixed government monitoring stations and mobile instruments mounted on taxis to map air quality across the city. The platform will automatically detect pollution hotspots and deliver this information to enforcement officers through a simple app. As a result, over 400 hotspots are now being reported each month to inspectors, and this is likely to improve further as the system continues to be tested.[181]

176 Bublitz et al. (2019).

177 Bublitz et al. (2019).

178 Santillana et al. (2015).

179 Morawska et al. (2018).

180 Ministry of Ecology and Environment (2022d); Ruizhen (2013).

181 Whitney & Qin (2021).

6. URBAN CITY EXAMPLES FROM CALIFORNIA AND CHINA

This section provides examples of how cities in California and China are tackling the synergies in practice. The case of Los Angeles illustrates effective regional and cross-agency coordination, the inclusion of explicit public health motivations as part of air and climate policy actions, and the consideration of environmental justice and vulnerability considerations in policymaking. The examples of Beijing and Shenzhen share lessons of coordinated regional action, as well as the "coordinated control" of air pollutants and GHG emissions, along with extensive air monitoring systems, and the role of carbon markets in decoupling economic development from carbon emissions.

6.1 Case Study: Los Angeles

Introduction

Located in southern California, Los Angeles County contains the second most populated city in the U.S., and spans more than 4,000 square miles.[182] As of 2021, 9.83 million people lived there—nearly a quarter of California's population.[183] For clarity, all references to Los Angeles in this report refer to Los Angeles County unless otherwise indicated.

Los Angeles has historically suffered from some of the worst air quality in the U.S.[184] This has been attributed to several causes: industrial pollution, vehicle emissions, poor waste management practices (including backyard incineration), and a geography and topography subject to atmospheric temperature inversions.[185] In 1947, the Los Angeles County Air Pollution District—the first of its kind in the U.S.—was formed, merging in 1967 with the Orange County, Riverside, and San Bernardino air pollution control districts to form the South Coast Air Quality Management District (SCAQMD).[186] Early air pollution controls in the 1940s and 1950s included banning backyard incinerators, reducing factory smoke, and cutting sulfur dioxide from refineries.[187] Subsequently, more stringent standards were adopted, including the reduction of hydrocarbons, the regulation of motor vehicles, and the reformulation of gasoline to include fewer smog-forming ingredients.[188] In the late 1980s, SCAQMD began promoting cleaner energy through fuel cells and electric vehicles.[189]

Climate change is an equally pressing issue for the county. Los Angeles County's Department of Public Health has noted that hotter, longer, heat waves are among its major threats. Such heat, along with the drought that large parts of California faced in recent years, is a testament to the impacts of climate change.[190] These have spurred the formation of regional collaboratives such as the Los Angeles Regional Collaborative for Climate Action and Sustainability (LARC) in 2007, which supports climate science, policy, and planning efforts across sectors.[191] The Department of Public Health also has issued the *Framework for Addressing Climate Change in*

182 U.S. Census Bureau (n.d.).

183 U.S. Census Bureau (n.d.).

184 South Coast Air Management District (2022).

185 South Coast Air Management District (n.d.-b).

186 South Coast Air Management District (n.d.-b).

187 South Coast Air Management District (n.d.-b).

188 South Coast Air Management District (n.d.-b).

189 South Coast Air Management District (n.d.-b).

190 Maizlish et al. (2017).

191 Los Angeles Regional Collaborative for Climate Action and Sustainability (2014).

Los Angeles County, which outlines how climate intersects the mission of local agencies and provides guidance on developing climate plans.[192]

In the City of Los Angeles, climate change has long been on the prioritized agenda of the mayor. In 2007, the City of Los Angeles Mayor's office published *Green LA: An Action Plan to Lead the Nation in Fighting Global Warming*.[193] This evolved into the *Sustainable City Plan*, also known as the *Green New Deal*, under former Mayor Eric Garcetti. A study identified several drivers of Los Angeles's strong focus on climate change: (1) the impetus to provide leadership on the issue, both within the city and at the national and international levels; (2) the need to address outdated and insufficient urban infrastructure; (3) the need to change behavior, especially on energy and water use in the built environment; and (4) strong existing partnerships with environmental and industry stakeholders, as well as local community, as seen in the formation of environmental coalitions.[194]

Air Quality and Climate Governance in Los Angeles

The main air regulatory agency in Los Angeles is the SCAQMD, responsible for curbing stationary source emissions through *Air Quality Management Plans,* which are blueprints for state and federal compliance.[195] Other regulatory agencies include CARB and EPA. SCAQMD is focused on regulating criteria air pollutants such as ozone, PM, NO_x, lead, CO, and SO_2, along with air toxics. The SCAQMD is primarily responsible for regulating stationary sources, but can also regulate some mobile sources such as the "indirect sources" within its jurisdiction—for example, ports and airports, as ships and aircraft are projected to be among the largest sources of NO_x in Southern California by the mid-2030s.[196]

Additionally, while SCAQMD has no direct climate authority, it works closely with CARB in implementing the SIPs through the *Air Quality Management Plans*, which affect climate mitigation and help meet ozone and $PM_{2.5}$ standards. SCAQMD also evaluates how climate change affects future concentrations of air pollutants.

The Governing Board of SCAQMD also enables cross-governmental coordination, as it is comprised of county supervisors and city representatives alike. These allow SCAQMD's plans to be implemented at both the county and city levels.

Los Angeles's climate change policies are also governed by multiple agencies, including the Los Angeles County Chief Sustainability Office, and, at the city level, the Office of the Mayor. The Chief Sustainability Office provides coordinated policy support and guidance for sustainability issues,[197] which include both air quality and climate change policies. This office authors the Los Angeles *OurCounty Plan* (also known as the "*Los Angeles Countywide Sustainability Plan*"), a non-legally binding strategic regional sustainability plan for Los Angeles.[198] Indicators under the plan were identified in consultation with the Department of Public Health, and the Chief Sustainability Office coordinates between county departments to ensure cross-sectoral goals are achieved. Further, the Chief Sustainability Office has a community engagement process for projects that may affect local communities and/or workers.

Los Angeles places a large focus on environmental justice issues. The Climate Equity Los Angeles series aims to center environmental justice in climate goals through community engagement.

192 Los Angeles County Department of Public Health (2014).

193 Schroeder (2011).

194 Schroeder (2011).

195 South Coast Air Quality Management District (n.d.-c).

196 At times there are trade-offs between addressing carbon emissions and addressing NOx emissions, as certain climate policies can actually increase PM and NOx emissions, so co-management of the sources is vital.

197 Los Angeles County Chief Sustainability Office (n.d.).

198 Los Angeles County Chief Sustainability Office (2019).

Moreover, this can be seen in a multitude of policies across the county, particularly in the OurCounty plan, which directed the preparation of the *Climate Vulnerability Assessment*.[199] The *Climate Vulnerability Assessment* identifies communities that are at high risk of climate exposure and have an increased risk of outcomes. Such vulnerabilities include negative health outcomes, inequities in infrastructure and access, institutionalized bias, and exposure to climate hazards such as wildfires and extreme heat. Some of the public health indicators included in the *Climate Vulnerability Assessment* are excess deaths and hospitalizations. The city of Los Angeles noted that a Climate Pollution Reduction Grant was instrumental in their ability to revisit goals and metrics within the *Climate Vulnerability Assessment*.[200]

As a follow-up to the *Climate Vulnerability Assessment*, the Los Angeles County Chief Sustainability Office partnered with the County Department of Public Health to publish a *Climate Change and Health Equity* report, which sets out concrete goals to foster healthier and increasingly resilient communities across Los Angeles. The report comprises four goals encompassing public education, sustainable communities, resilience, and engaged public health programs, and highlights Los Angeles's integrated approach to addressing both climate and public health concerns.

In the city of Los Angeles, the Office of the Mayor published Los Angeles's Green New Deal, which is also called the "Sustainable City pLAn." First introduced in 2015, and later updated in 2019, the plan sets out broad policies, ranging from securing clean air, water, and a stable climate; to improving community resilience and access to healthy food and open space; to climate justice.[201] At the city level, the Office of Climate Emergency Mobilization was also established to collaborate with the city's departments and bureaus to mitigate climate emergencies such as extreme heat.[202]

In the unincorporated areas of Los Angeles, Los Angeles County Planning performs all land use planning functions and implements the Climate Action Plan. The *2045 Climate Action Plan* for Los Angeles—which aims to achieve carbon neutrality by 2045 through GHG emission reductions—recently underwent public review, culminating in May 2023.[203] The plan is an enforceable document, which will be appended to Los Angeles County's General Plan, and is anticipated to be updated every five years. The Los Angeles County Department of Regional Planning, the plan lead, has also elaborated that public health was a co-benefit considered in reaching the plan's emission reduction goals.

Finally, the Los Angeles Department of Public Health has increasingly adopted a climate change lens in its public health policies and sought to coordinate Los Angeles's climate change efforts from a public health angle. In particular, the department is concerned about climate change impacts, such as extreme heat, worsening air quality, wildfires, and mosquito-borne diseases.[204] In 2014, the department convened a county-wide committee focused on climate change mitigation and adaptation, with an initial focus on reducing the impacts of the urban heat island effect in Los Angeles.[205]

Key Indicators

This subsection focuses on the public health indicators included in three key Los Angeles policies: (1) the South Coast Air Quality Management District's *Air Quality Management Plan*; (2) Los Angeles's *OurCounty Plan*; and (3) Los Angeles's *Green New Deal*. These policies were chosen for their strong focus on public health co-benefits, and effects on air quality and climate change policies. They also set out comprehensive public health indicators that are used to monitor the co-benefits of air quality and climate change policies in Los Angeles.

199 Los Angeles County Chief Sustainability Office (2021).

200 LA City Mayor's Office, personal communication (March 2023).

201 City of Los Angeles (2019).

202 Climate Emergency Mobilization Office (n.d.).

203 Los Angeles County Department of Regional Planning. (n.d.).

204 Los Angeles Department of Public Health (2023).

205 Los Angeles Department of Public Health (2023).

Health Indicators in the South Coast Air Quality Management District Air Quality Management Plan

SCAQMD's *Air Quality Management Plan* is a regional blueprint to achieve federal and state ambient air quality standards.[206] Most recently updated in 2022, it addresses the requirements for meeting EPA's 2015 NAAQS for ground-level ozone, particularly in the South Coast Air Basin and Coachella Valley.[207] Attaining the NAAQS for ozone requires the reduction of nitrogen oxides, a precursor to ozone.[208] The 2022 Plan thus predominantly addresses ozone and NO_x, but also assesses other criteria air pollutants like PM_{10} and $PM_{2.5}$, CO, SO_2, and lead.[209]

The health effects of air pollution are well documented in the plan, with Chapter 2 focused on "Air Quality and Health Effects." The plan's Appendix I comprehensively tracks scientific findings on the health effects of ambient air pollutants. The health effects tracked are informed by scientific reviews, as well as additional information from recently published academic studies. The indicators are identified from current research on various pollutants, including ozone, $PM_{2.5}$, PM_{10}, ultrafine particles, NO_2, and SO_2. Beyond those pollutants, Appendix I also tracks the health effects of CO, lead, toxic air contaminants, diesel PM, VOCs, and odors. The plan tracks mortality indicators such as total mortality, respiratory mortality, and cardiovascular mortality. Morbidity indicators relating to respiratory effects, cardiovascular effects, metabolic effects, nervous system effects, reproductive effects, and cancer are also tracked. The short-term and long-term morbidity effects of exposure to different pollutants are often distinguished. Examples of specific indicators include respiratory-related hospital admissions and Emergency Department (ED) visits for aggregated respiratory-related disease, development of asthma and asthma symptoms, and heart failure. A list of the health indicators from the SCAQMD's *Air Quality Management Plan* is provided in Annex III of this report.

The tracking of these health effects then informs SCAQMD's Socioeconomic Analysis under the *Air Quality Management Plan*, which evaluates the cost and other economic impacts of the policies under the plan. For example, the latest analysis estimates that the achievement of air pollution goals in the South Coast would save about $19 billion. The health indicators in the plan are used to help SCAQMD model the costs and benefits of clean air and their impacts on the local economy. Finally, it should be noted that SCAQMD collects health data but does not collect air quality and meteorological data. It also has a comprehensive monitoring and modeling study called the Multiple Air Toxics Exposure Study (MATES), which calculates the carcinogenic risk from exposure to air toxics spatially. MATES includes a fixed site monitoring program with 10 stations, an updated inventory of toxic air contaminants, and a modeling effort to characterize risk across the Basin. The initiative offers updates approximately every six years and has inspired the EPA to conduct similar studies such as its Air Toxics Screen.

Health Indicators Used in the Los Angeles OurCounty Plan

The 2019 Los Angeles *OurCounty Plan* sets out a long-term sustainability vision for the county, comprising 12 cross-cutting goals. The plan serves to coordinate local action and establishes more than 60 priorities to be implemented by various departments, such as the Department of Public Health and the Department of Regional Planning. It consists of goals that acknowledge the importance of public health and are rooted in creating healthy communities.[210]

206 South Coast Air Management District (2022).

207 South Coast Air Management District (2022).

208 South Coast Air Management District (2022).

209 South Coast Air Management District (2022).

210 Los Angeles County Chief Sustainability Office (2019).

The plan incorporates public health targets (i.e., to decrease childhood asthma prevalence to 6.8% by 2025, 6.0% by 2035, and 5.0% by 2045 from a baseline of 7.5% in 2015).[211] This seeks to achieve its strategy of minimizing the exposure of vulnerable populations to pollution and reducing health disparities.[212] Childhood asthma was selected, given that there is greater sensitivity to air pollution in children.[213] A full list of the public health indicators incorporated in the plan is provided in Table 12.

TABLE 12 | Public Health Indicators in the Los Angeles OurCounty Plan[214]

Type of indicator	Indicator(s)	Source
Morbidity	Prevalence of Heart Disease / Heart Disease Preconditions and Diabetes	Los Angeles County Department of Public Health, Office of Health Assessment and Epidemiology
	Percent of Children (0–17 years old) with Current Prevalence of Asthma	Los Angeles County Department of Public Health, Office of Health Assessment and Epidemiology
	Heat Stress Emergency Department Visits	Los Angeles County Department of Public Health/ Office of State-wide Health Planning and Development
	Overall Air Toxics Cancer Risk and Diesel Risk from SCAQMD MATES studies (with equity evaluation)	SCAQMD Multiple Air Toxics Exposure Studies

Public Health Indicators in the Green New Deal / Sustainable City Plan

Los Angeles's *Sustainable City pLAn* was first released in 2015 and is slated to be updated every four years.[215] The 2019 update is the focus of this subsection; it elaborates on the city's vision for a sustainable future and focuses on climate with accelerated goals.[216] The pLAn includes public health components, including measures to quantify health outcomes from air quality improvements,[217] as well as to highlight how different aspects will benefit citizens.[218] One indicator is "Health and Wellbeing," which covers the improvement of air quality, comfort, and mental health, and the encouragement of physical activity.[219] The pLAn elaborates that it quantifies the public health benefits of enhanced air quality, which is assisted by SCAQMD. Indicators that are measured include avoided mortality and avoided hospital visits.[220] The public health indicators in the pLAn were chosen after consulting CalEnviroScreen, which monitors health metrics such as asthma, low birth rates, and incidences of cardiovascular disease. Metrics such as asthma-related emergency department visit rates in children were specifically taken from CalEnviroScreen and used to inform the goals under the pLAn.

Annex IV highlights the public health benefits of the Los Angeles *Green New Deal*. In addition to the public health co-benefits, many of these targets also highlight that air pollution will be

211 Los Angeles County Chief Sustainability Office (2019).
212 Los Angeles County Chief Sustainability Office (2019).
213 County of Los Angeles, Sustainability Office, personal communication (March 2023).
214 Los Angeles County Chief Sustainability Office (2019).
215 City of Los Angeles (2019).
216 City of Los Angeles (2019).
217 City of Los Angeles (2019).
218 City of Los Angeles (2019).
219 City of Los Angeles (2019).
220 City of Los Angeles (2019).

reduced. This demonstrates that the pLAn recognizes both the air quality and public health co-benefits that may be derived from emission reduction strategies.

Use of Decision-Analysis Technologies Tools in the Los Angeles Context

Predicting What We Breathe

The Predicting What We Breathe project is a two-year initiative aimed at contributing to the City of Los Angeles's policy goals of mitigating the effects of air pollution by developing machine learning algorithms and big data analytics through predictive air quality monitoring. A collaboration between the city, NASA, California State University Los Angeles (CSULA), and Open AQ, it utilizes time-series measurements to inform appropriate measurements, analytics, predictive algorithms, and mitigation strategies. Its goal is to enable forecasting of air pollution events, identify similarities among global megacities, and create an open-source $PM_{2.5}$ stack for data integration. It emphasizes the importance of collaboration between wide-ranging data sources, as air pollution events are not static within jurisdictional boundaries. Machine learning for air pollution prediction is an emerging field, with several similar projects reporting results from Hong Kong and Lanzhou, China.[221]

CalEnviroScreen Vulnerability Mapping

California's OEHHA developed CalEnviroScreen, which uses census data to map environmental, socioeconomic, and health data to rank community vulnerability. Now in its fourth edition, the tool's indicators can be grouped into: exposure, environmental effects, sensitive populations, and socioeconomic factors. Direct health indicators, which fall under the "sensitive populations" category, include morbidity indicators like asthma and cardiovascular diseases, and other indicators such as low birth weight. Rates of asthma and cardiovascular diseases are measured through prevalence, emergency department visits, and deaths. CalEnviroScreen is also capable of looking at the intersection of vulnerability across key indicators.[222] The City of Los Angeles consults CalEnviroScreen to help assess where to prioritize the implementation of key municipal climate programs, including the Cool Pavement program, Air Purifier Giveaway program, and heat mitigation programs, using the mapping as a decision-maker analysis support tool.[223]

Watts Rising Air Quality Monitoring Program

Watts Rising connects local air quality monitoring within the Watts neighborhood to inform future sustainable infrastructure investments, including green and low-carbon infrastructure sharing, home weatherization, and other climate actions. Under the program, the City Bureau of Street Lighting has established air quality monitors to assess the impacts on air quality outcomes.[224]

Lessons Learned from Los Angeles

First, jurisdictions may assess the latest science to ensure that policies are informed by public health co-benefits. The SCAQMD Air Quality Management Plan models a way in which research and air quality progress can be consistently monitored. Policies can then be informed by public health considerations, such as those identified through SCAQMD's Socio-Economic Analysis, which evaluates the economic cost of these public health effects. In other words, some baseline science must be established in order for public health co-benefits to be incorporated into policies. However, it is also recognized that it might be difficult to obtain granular data. The lack of data with regard to specific health impacts could pose an issue. Beyond specific health impacts, there may be issues with the granularity of data on a geographic level. Depending on how data are collected, data might be available

221 R. Guo et al. (2022); Wai & Yu (2023); Yang et al. (2021).

222 LA City Mayor's Office, personal communication (March 2023).

223 LA City Mayor's Office, personal communication (March 2023).

224 LA City Mayor's Office, personal communication (March 2023).

only at the county level and not the city level, especially since departments such as the Department of Public Health are only set up at the county level. There is thus a need to develop technology to ensure more specific public health monitoring can be carried out.

Next, public health co-benefits can serve as measurable, quantitative goals within climate and air quality policies. The LA *OurCounty Plan's* public health targets are a good example since the plan has an explicit target of decreasing childhood asthma prevalence by minimizing vulnerable populations' exposure. The County Chief Sustainability Office also aims to update the *OurCounty Plan* indicators in 2025, based on updated data from relevant agencies, including the Department of Public Health. Under the City of Los Angeles's *Sustainable City pLAn*, the City of Los Angeles Mayor's Office provides annual updates, which track progress. Updates are coordinated with different departments in the City of Los Angeles and beyond (such as the California Department of Public Health and the Los Angeles County Department of Public Health), and enable regular interagency check-ins.

Finally, expected public health co-benefits may be incorporated into policies to obtain better buy-in from the intended beneficiaries. Los Angeles's strong environmental justice emphasis in its climate policies, in particular, serves this function and ensures that policies actually benefit their target audiences.

6.2 Case Study: Beijing

Introduction

Located in northern China, the capital city of Beijing is among the world's most populous, with a population exceeding 21 million residents. Beijing has experienced significant growth in industrialization, urbanization, and motorization,[225] resulting in increased energy consumption and pollutants, with detrimental effects on air quality, human health, and the surrounding ecosystem.[226] Particulate matter—particularly high concentrations of $PM_{2.5}$—has emerged as the primary concern in Beijing's air pollution,[227] with approximately 42% of $PM_{2.5}$ originating from surrounding regions, and 46% of local emissions attributed to vehicle emissions, as of 2020.[228] Beijing has implemented stringent measures to mitigate $PM_{2.5}$ and improve air quality, including formulating the *Clean Air Action Plan* and *Air Pollution Prevention and Control Regulations* based on national policies and regulations. The government also has emphasized six key actions in air pollution prevention and control, encompassing strategies to reduce motor vehicle pollution, coal-fired pollution, highly polluted industries, and fugitive dust pollution, and promote ecological restoration and recovery and novel technologies in environmental protection.[229] Further, the Beijing government has released 42 local standards for air pollution control. These have yielded significant results, evidenced by a 66.5% decline in the annual average concentration of $PM_{2.5}$ to 30 $\mu g/m^3$ in 2020, compared to 2013. Moreover, mobile source $PM_{2.5}$ emissions have been reduced by 41% since 2018.[230]

Besides air pollution, climate change has adverse effects on Beijing, particularly affecting the energy system and public health. The impacts of climate on the energy system are three-fold: high temperatures strain the power supply by exceeding maximum load, low temperatures result in a scarcity of natural gas, and extreme weather jeopardizes energy production, supply, and transportation.[231] Additionally, heat waves and high temperatures significantly heighten the risk of non-accidental deaths and exacerbate respiratory and circulatory illnesses, with women, middle-aged and elderly individuals, and those with limited education being particularly vulnerable.[232]

225 Han et al. (2014).

226 W. Li et al. (2011, 2014).

227 Hu et al. (2014).

228 Beijing Municipal Ecology and Environment Bureau (2021).

229 H. Zhang et al. (2016).

230 The People's Government of Beijing Municipality (2021a).

231 Sha et al. (2017).

232 Yanlin et al. (2022).

Scientific evidence confirms that climate change exacerbates Beijing's air pollution issues.[233] Beijing has prioritized green, circular, and low-carbon development in alignment with national targets. It pioneered the "dual control" mechanism, managing both the overall amount and intensity of energy consumption and carbon emissions while promoting resource conservation, environmental protection, and climate change response. Notably, during the 13th Five-Year Plan period, Beijing achieved a reduction of more than 23% in energy consumption intensity, and over 26% in carbon emission intensity, maintaining overall stability in carbon emissions.[234] The success can be attributed to six major approaches: (1) development of innovation-driven, low-emission industries; (2) establishment of a low-carbon energy consumption structure dominated by electricity and natural gas; (3) implementation of low-carbon projects in key sectors, including low-carbon buildings, transportation, and technologies and forest carbon sequestration; (4) effective regulation, development, and enforcement; (5) establishment of a carbon market to promote industrial structure upgrading, transportation decarbonization, and energy system carbon mitigation; and (6) active public participation in low-carbon-promoting activities such as Low-Carbon Day and green travel.[235] Beijing has also released the *14th Five-Year Plan for Climate Change and Energy Conservation*,[236] along with the *2023 Action Plan to Address Climate Change*,[237] both of which aim to stabilize and reduce carbon emissions.

Under national guidance,[238] Beijing has been implementing "coordinated control" policies to address the problem of air pollution and GHG emissions simultaneously. Three types of "coordinated control" have been adopted: (1) "coordinated control" of $PM_{2.5}$ and ozone, (2) "coordinated control" of air pollution and GHG emissions, and (3) "coordinated control" of air pollution among different cities in the Beijing-Tianjin-Hebei region.[239] Many targets and measures outlined in Beijing's air pollution and climate change policies implement "coordinated control." For example, targets for air quality (such as $PM_{2.5}$ concentration, NO_x mitigation amount, and number of days with good air quality) and targets for climate change mitigation (such as reduction targets for gross carbon emissions, carbon intensity, and energy intensity) were outlined in Beijing's 14th FYP for ecology and environmental protection.[240] Three measures—clean manufacturing, adjusting the industrial structure, and adjusting the energy structure—have been implemented to achieve the "coordinated control" of different air pollutants ($PM_{2.5}$ and ozone) and between air pollution and GHG emissions.[241] Moreover, various financial incentives, such as financial support for the green industry and carbon market, were mentioned in Beijing's 14th FYP for climate change mitigation and energy saving to support "coordinated control" policies.[242] Finally, Beijing has established a three-dimensional network, which consists of a ground station, vertical monitoring station, and satellites for the monitoring and forecasting of air quality and GHGs.

Finally, the public health co-benefits of air pollution control and climate change mitigation have been recognized by Beijing's government and emphasized in important policy documents. For example, Beijing's 14th FYP for healthy Beijing construction mentioned that it is important to "win the battle of pollution prevention and control and strengthen the coordinated control of air pollutants and GHGs."[243] Additionally, Beijing's 14th FYP for climate change mitigation and energy savings required an assessment of the impact of climate change on public health.[244]

233 Cai et al. (2017).

234 Beijing Municipal Ecology and Environment Bureau (2022).

235 Beijing Municipal Ecology and Environment Bureau (2022).

236 Beijing Municipal Ecology and Environment Bureau (2022).

237 The People's Government of Beijing Municipality (2023).

238 Central Committee of the Chinese Communist Party & State's Council (2021a).

239 The People's Government of Beijing Municipality (2021b).

240 The People's Government of Beijing Municipality (2021c).

241 The People's Government of Beijing Municipality (2023).

242 Beijing Municipal Ecology and Environment Bureau (2022).

243 The People's Government of Beijing Municipality (2021a).

244 Beijing Municipal Ecology and Environment Bureau (2022).

Air Quality and Climate Governance in Beijing

The leading government agency in charge of air quality management in Beijing is the Beijing Municipal Ecology and Environment Bureau (BMEEB). The responsibilities of BMEEB include setting targets for air quality management based on national-level FYPs, implementing air pollution abatement, and monitoring air quality. BMEEB also coordinates with many other government agencies to manage air quality. These departments include the government of districts in Beijing, the Beijing Municipal Commission of Transport, the Beijing Municipal Commission of Development and Reform, the Beijing Municipal Bureau of Economy and Information Technology, and others. Together, these government agencies take actions to curb air pollutant emissions, promote clean-energy vehicles, monitor mobile source emissions, and finally achieve the air quality targets outlined in Beijing's 14th FYPs.[245]

On the other hand, the major government agencies governing Beijing's climate policies are the Beijing Municipal Ecology and Environment Bureau (BMEEB) and the Beijing Municipal Development and Reform Commission (BMDRC). BMEEB is in charge of setting targets for GHG emission reduction based on national-level FYPs, improving the legal framework for climate change mitigation, and developing the carbon market, while BMCDR is in charge of developing Beijing's "1+N" policy framework for carbon peaking and neutrality and surveilling the control of gross carbon emissions and carbon intensity. Similar to the air quality governance mentioned before, many other governmental departments also participate in implementing climate change policies in Beijing.[246]

We additionally note that the Beijing Municipal Health Commission (BMHC) participates in some climate change mitigation activities. For example, according to a plan released in 2023, BMHC will assist in the formulation of the Beijing climate adaptation plan.

TABLE 13 | Indicators Related to Public Health in Beijing's 14th Five-Year Plan for Ecology and Environmental Protection [247]

Indicator	Target Value by 2025	Mandatory or Not
$PM_{2.5}$ annual average concentration (μg/m³)	35	Mandatory
The ratio of days with good air quality (Air Quality Index (AQI)≤100)	Gradually increase	Mandatory
The ratio of heavily polluted days (AQI > 200)	Almost eliminated	Not Mandatory
NO_x emissions reduction (10,000 metric tonnes)	More than 1.38	Mandatory
VOCs emissions reduction (10,000 metric tonnes)	More than 0.99	Mandatory

Key Indicators

Most of the indicators related to public health are outlined in Beijing's different 14th FYPs. This subsection will focus on health-related indicators in three of Beijing's 14th FYPs.

In Beijing's 14th FYP for ecology and environmental protection, there are several indicators related to reducing the impact of air pollution on public health (Table 13).[248] These indicators

245 The People's Government of Beijing Municipality (2023).

246 The People's Government of Beijing Municipality (2023).

247 The People's Government of Beijing Municipality (2021c).

248 The People's Government of Beijing Municipality (2021c).

were selected based on the targets in the national 14th FYP[249] and the "guiding principles" of this plan, which include environmental protection and public health improvements. The selection of NO_x and VOCs as indicators shows that Beijing plans to implement the "coordinated control" of both $PM_{2.5}$ and ozone since NO_x and VOCs are important precursors of $PM_{2.5}$ and ozone. Even though no direct public health indicators, such as avoided mortality and avoided morbidity related to air pollution, were included in this plan, the indicators in Table 13 can still be used to evaluate and demonstrate the public health benefit of air quality improvements, as well as the impact of the "coordinated control" of air pollution and GHG emissions. These indicators are monitored by the Beijing Municipal Ecological and Environmental Monitoring Center.

TABLE 14 | Indicators Related to Public Health in Beijing's 14th FYP for Climate Change and Energy Conservation[250]

Indicator	Target Value by 2025	Mandatory or Not
Total Coal Consumption (Million Metric Tonnes)	Less than 1	Mandatory
The percentage of renewable energy in gross energy consumption	More than 14.4%	Mandatory
Decrease in energy consumption per 10,000 yuan of industrial added value	12%	Mandatory
Forest Coverage Rate	45%	Not mandatory

There are also indicators in Beijing's 14th FYP for climate change and energy conservation that are related to the public health benefits of air pollution control and climate change mitigation (Table 14).[251] Similar to the FYP for ecology and environmental protection, the indicators in this plan were also selected based on targets in the national 14th FYP.[252] Most of these indicators can help assess the effectiveness of the "coordinated control" of air pollution and GHG emissions and thus can be used to evaluate the public health impact of the "coordinated control" policies. These indicators are monitored by the BMEEB and BMDRC.

TABLE 15 | Indicators Related to the Impact of Air Pollution and Climate Change in Beijing's 14th FYP for "Healthy Beijing Construction"[253]

Indicator	Target Value by 2025	Mandatory or Not
Premature mortality of chronic diseases (including cardiovascular disease, cancer, chronic respiratory disease, etc.)	Gradually decrease	Not mandatory
Infant mortality	Decrease to internationally low level	Not mandatory

However, according to the "guiding principles" of this plan, it should be noted that these indicators were chosen with the aim of achieving carbon peaking and neutrality, increasing carbon sinking, and improving energy efficiency,[254] which means that public health benefits were not explicitly part of the motivation for Beijing's climate change policies.

249 The National People's Congress of the People's Republic of China (2021).

250 Beijing Municipal Ecology and Environment Bureau (2022).

251 Beijing Municipal Ecology and Environment Bureau (2022).

252 The National People's Congress of the People's Republic of China (2021).

253 The People's Government of Beijing Municipality (2021a).

254 Beijing Municipal Ecology and Environment Bureau (2022).

Finally, Beijing's 14th FYP for "healthy Beijing construction" includes some indicators that are related to the impacts of air pollution and climate change (Table 15).[255] Since it is scientifically indicated that air pollution and climate change can exacerbate chronic diseases and infant mortality, these indicators can reflect the effectiveness of Beijing's air and climate change policies. Moreover, these indicators were chosen according to the targets in the national 14th FYP.[256] These indicators are monitored by the Beijing Municipal Health Commission.

6.3 Case Study: Shenzhen

Introduction

Shenzhen, as the pioneering special economic zone (SEZ) in China, has garnered significant attention due to its remarkable and rapid development since its establishment in 1980. Within the last three decades, this once modest town has undergone an extraordinary transformation into a bustling megacity, witnessing a 30-fold population surge and a significant increase in its GDP.[257] According to the latest official data from 2022, the year-end permanent population stood at approximately 17.66 million, while the GDP amounted to about 3238.768 billion Chinese yuan (equivalent to approximately 448 billion U.S. dollars).[258]

Like other megacities around the world, Shenzhen has experienced significant growth in both urbanization and industrialization, as well as growth in population and energy consumption in the past decades. The rapid growth of Shenzhen resulted in air pollution problems. The number of haze days kept increasing and peaked in 2004 when the number of haze days reached 187 in that year. The annual average concentration of $PM_{2.5}$ also increased and peaked in 2006 when the $PM_{2.5}$ concentration reached 62 $\mu g/m^3$.[259] The biggest air pollution source, coal power generation, as well as other sources such as mobile vehicles, cargo shipping, and ports, also generate large amounts of GHG emissions.[260]

However, over the last decade, Shenzhen has simultaneously achieved carbon emission reductions, air quality improvements, public health improvements, and rapid economic growth. Since 2005, Shenzhen has managed to mitigate air pollution while maintaining economic development concurrently, as the annual average concentration of most air pollutants, except ozone, has shown an overall downward trend,[261] and Shenzhen's GDP has grown five-fold.[262] Moreover, Shenzhen's carbon emissions per 10,000 yuan of GDP have steadily declined year by year, and its emissions are significantly lower than the national average. Shenzhen has outpaced the energy-saving and emission-reduction tasks assigned by the state and Guangdong Province and is ahead of other large and medium-sized cities in the country.[263] Nowadays, Shenzhen is a city with a population of tens of millions with the best ambient air quality in China,[264] and its carbon emissions per 10,000 yuan of GDP in 2020 is about one-fifth of the national average.[265]

Four key types of measures have been adopted by Shenzhen to conduct "coordinated control" between air pollution and GHG emissions while improving public health and maintaining high-speed economic development: (1) air pollution and carbon sources identification; (2)

255 The People's Government of Beijing Municipality (2021a).
256 The National People's Congress of the People's Republic of China (2021).
257 L. Li et al. (2015).
258 Statistics Bureau of Shenzhen Municipality (2023).
259 Caixia (2017).
260 Harbin Institute of Technology (Shenzhen) et al. (2019).
261 Harbin Institute of Technology (Shenzhen) et al. (2019).
262 Statistics Bureau of Shenzhen Municipality (2022).
263 Harbin Institute of Technology (Shenzhen) et al. (2019).
264 Harbin Institute of Technology (Shenzhen) et al. (2019).
265 Shenzhen Municipal People's Government (2022a).

adjustment of industrial, energy, transportation, and building structures; (3) high-quality development mechanism innovation; and (4) regional collaboration.

Shenzhen is a pioneering city in China undertaking $PM_{2.5}$ source analysis. Commencing in 2004, Shenzhen allocated substantial scientific research funding to support efforts by institutions such as Peking University to conduct comprehensive atmospheric science research, including $PM_{2.5}$ source analysis. This research proved successful in identifying the characteristics and primary sources of air pollution in the region. To achieve accurate pollution control, Shenzhen also established a cutting-edge monitoring system for ambient air quality, enabling the collection of near-surface data to discern pollutant origins and facilitate precise pollution management.[266] In addition to advancements in air pollution source analysis, Shenzhen has also made significant investments in carbon inventory development, which led to the identification of major GHG sources, including those attributed to power generation, transportation, building activities, and manufacturing processes.[267]

Shenzhen has implemented significant pollution control programs and initiatives, building upon the findings of source identification, to effectively enhance air quality, mitigate GHG emissions, and improve public health. The city has made remarkable strides in adjusting its industrial, energy, transportation, and building structures to achieve these goals. By eliminating industries with "high energy consumption, high pollution emission, low economic efficiency," such as cement production, paper production, and printing and dyeing,[268] and promoting "innovative industries" like internet, information technology, new energy, and new materials,[269] Shenzhen has successfully improved its industrial structure. Moreover, measures to increase power generation from renewable sources and to transition from oil and coal to nuclear energy and natural gas have contributed to a more sustainable energy structure.[270] The adjustment of both industrial and energy consumption structures significantly lowered levels of air pollution and carbon emissions in Shenzhen.[271]

In addition, Shenzhen also has taken measures to reduce air pollution and carbon emissions from the transportation and building sectors. Shenzhen's commitment to transportation sector improvements includes actively promoting mobile vehicle electrification and reducing air pollution from off-road mobile machinery. It is estimated that the promotion of electric vehicles in Shenzhen can prevent 400–700 cases of premature death.[272] Moreover, as an important port city, Shenzhen has also introduced port electrification and shipping air pollution monitoring to effectively reduce pollution and carbon emissions from the shipping sector.[273]

Furthermore, Shenzhen has prioritized building energy efficiency by enacting China's first building energy-saving regulations in 2006, and encouraging the construction of near-zero-energy buildings, zero-carbon buildings, and near-zero-carbon emission pilot areas, resulting in reduced carbon emission intensity and total carbon emissions from buildings. As a result, Shenzhen now stands as one of the leading cities in China with a substantial scale and density of green buildings, further contributing to its environmentally conscious and sustainable development endeavors.[274]

In addition to structural enhancements in the industrial, energy, transportation, and building sectors, Shenzhen has taken significant strides by adopting a carbon trading system and

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266 Caixia (2017).

267 Green & Low-Carbon Development Foundation, 2016; Harbin Institute of Technology (Shenzhen) et al. (2019).

268 Jie (2017).

269 Chunnan et al. (2015).

270 Legislative Council of Hong Kong (2022, p. 20).

271 Harbin Institute of Technology (Shenzhen) et al. (2019).

272 Ye et al. (2020).

273 Jie (2017).

274 Congcong (2023).

implementing green financing mechanisms to effectively drive GHG mitigation. As one of the pioneering regions to embrace emissions trading, Shenzhen inaugurated China's first carbon trading market in 2013, a market that has since emerged as the most active in the country, maintaining the highest carbon emission quota transaction rate[275] for nine consecutive years as of 2022. Notably, 99.87% of the 747 enterprises incorporated within Shenzhen's carbon trading market complied with their carbon emission limits by the end of 2021. Remarkably, the Shenzhen carbon market has led to an estimated 42.07% reduction in the average carbon emission intensity among the manufacturing enterprises within the market, while concurrently witnessing a 62.65% increase in industrial value-added, forming an ideal development trend of eco-economic decoupling.[276] The carbon market has also substantially contributed to air quality enhancement by reducing reliance on coal and promoting natural gas utilization for power generation. Furthermore, this market has facilitated the development of high-quality industries that demonstrate high economic efficiency and significantly lower pollution levels.[277] In addition to the carbon market, Shenzhen introduced China's first green finance scheme in 2020, encompassing the transparent disclosure of environmental information, the evaluation of sustainable investments, the establishment of institutional capacities, and the sanctioning of misconduct.[278] As a result of these measures, Shenzhen has successfully spurred local enterprises to play an active role in mitigating GHG emissions and pollution. An example is the National Development Bank's support for a waste incineration power generation project.[279]

Regional collaboration among cities in the Guangdong-Hong Kong-Macao Greater Bay Area (Greater Bay Area) also helps Shenzhen reduce air pollution and carbon emissions. The collaboration between Guangdong Province and Hong Kong on air pollution was the first in China and established the first regional air monitoring network and significantly reduced the air pollution from shipping, power generation, and manufacturing in the Greater Bay Area. Shenzhen actively participates in collaborative air pollution initiatives, engaging with cities like Dongguan, Huizhou, and Hong Kong to co-implement air pollution control measures, such as mobile vehicle emissions monitoring.[280] Additionally, Shenzhen assumes a leadership role in promoting low-carbon development within the Greater Bay Area. In 2022, the city unveiled an action plan for the development of a carbon footprint verification system in the region.[281] Shenzhen also leverages its innovative advantages in the energy technology field and helps other cities in the Greater Bay Area develop advanced technologies, such as new energy vehicles and advanced nuclear power.[282]

Finally, the public health co-benefits of air pollution control and climate change mitigation have been recognized by Shenzhen's government and emphasized in some important policy documents. For example, Shenzhen's 14th FYP for Public Health mentioned that it is important to pursue dual control of particulate matter and ozone, and it sets a target of annual average $PM_{2.5}$ concentration at 18 μg/m^3 for 2025.[283] Additionally, Shenzhen's 14th FYP for ecology and environment protection mentioned that it is important to study health risk, and promised to establish an air quality health index and "actively implement national environmental health management pilot projects".[284] Shenzhen's 14th FYP for climate change mitigation emphasized that Shenzhen should analyze the effects of extreme weather on morbidity, conduct research on vulnerable communities, and establish a health risk monitoring approach,[285] which is also

275 Carbon emission quota transaction rate = Carbon emission quota transaction ÷ Total carbon emission quota × 100%.

276 Shun (2023).

277 Harbin Institute of Technology (Shenzhen) et al. (2019).

278 Congcong (2023).

279 Everbright Environment (2021).

280 T. Xue et al. (2022).

281 Shenzhen Municipal People's Government (2022b).

282 Shenzhen Municipal People's Government (2022a).

283 Health Commission of Shenzhen Municipality (2022).

284 Shenzhen Municipal People's Government (2022c).

285 Shenzhen Municipal People's Government (2022a).

mentioned by Shenzhen Special Economic Zone Ecological Environment Protection Provisions.[286] Shenzhen's government also has conducted some research projects focusing on the public impact of air pollution and climate change. For example, in collaboration with the Chinese Center for Disease Control and Prevention, Shenzhen investigated the health impacts of air degradation in 2018.[287] Another example is the estimation of climate comfort[288] conducted by Shenzhen's government, which assesses the impact of climate change on air pollution while also evaluating the climate comfort level in different areas of Shenzhen and provides suggestions for public health impact evaluation, as well as public health adaptation to climate change.[289]

Air Quality and Climate Governance in Shenzhen

The leading government agency in charge of air quality management and climate change mitigation in Shenzhen is the Shenzhen Municipal Bureau of Ecology and Environment (SMBEE). Similar to the Municipal Ecology and Environment Bureau of Beijing, the responsibilities of the SMBEE include setting targets for air quality and GHG emission based on national-level FYPs, implementing air pollution and GHG abatement measures, monitoring air quality and GHGs, and enforcing laws and regulations. SMBEE also coordinates with many other government agencies. According to the draft version of the Shenzhen Blue Sky Sustainable Action Plan (2022–2025) and Shenzhen's 14th FYP for Climate Change, some departments include the government of districts in Shenzhen, the Shenzhen Municipal Bureau of Transportation, the Shenzhen Municipal Commission of Development and Reform, the Shenzhen Municipal Bureau of Economy and Information Technology, the Shenzhen Municipal Bureau of Housing and Construction, the Shenzhen Administration for Market Regulation, and others.[290] Together, these government agencies take actions to promote industrial structure upgrading, establish a clean energy system, develop green transportation, curb VOCs emissions, and finally achieve targets outlined in Shenzhen's 14th FYPs.

In addition, the Shenzhen Municipal Health Commission (SMHC) also participates in some air pollution control and climate change mitigation activities. For example, according to the Key Working Areas of Public Health in Shenzhen (2023), the SMHC will "aim to incorporate public health concern into all types of policies" and "conduct public health impact estimation for important planning, projects, and policies," which will likely include Shenzhen's action in mitigating air pollution and GHG emissions.[291]

Key Indicators

Most of the indicators related to public health are outlined in Shenzhen's different 14th FYPs. This subsection will focus on health-related indicators in three of Shenzhen's 14th FYPs.

In Shenzhen's 14th FYP for ecology and environmental protection, a comprehensive set of indicators concerning the reduction of air pollution's impact on public health has been delineated. These are featured in Table 16.[292] The selection of these indicators was based on the targets specified in the national 14th FYP[293] and steered by the "guiding principles" of the plan, which emphasize the importance of enhancing public health. By specifically incorporating NO_x and VOCs as indicators, Shenzhen aims to execute a coordinated approach to mitigating both $PM_{2.5}$ and ozone, given that NO_x and VOCs serve as crucial precursors to these pollutants. The indicators listed in Table 16 serve a crucial role in evaluating and showcasing the tangible benefits accrued to public health through improvements in air quality, alongside assessing the

286 Shenzhen Municipal People's Government (2021).

287 Guomin & Jiajia (2018).

288 Climate comfort refers to the level of comfort—experienced by healthy humans—provided by climatic factors, such as temperature, humidity, wind speed, and sunshine, without the aid of temperature control devices or sunscreen (D. Zhang et al. [2022]).

289 Meteorological Bureau of Shenzhen Municipality (2023a, 2023b).

290 Shenzhen Municipal Bureau of Ecology and Environment (2022); Shenzhen Municipal People's Government (2022a).

291 Shenzhen Municipal Health Commission (2023).

292 Shenzhen Municipal People's Government (2022c).

293 The National People's Congress of the People's Republic of China (2021).

impact of synchronized efforts in controlling air pollution and GHG emissions. These indicators are monitored by the Shenzhen Ecological and Environmental Monitoring Center. It should be noted, however, that direct public health indicators such as mortality and morbidity related to air pollution-induced diseases are not explicitly included in this plan.

TABLE 16 | Indicators Related to Public Health in Shenzhen's 14th Five-Year Plan for Ecology and Environmental Protection [294]

Indicator	Target Value by 2025	Mandatory or Not
$PM_{2.5}$ annual average concentration (μg/m^3)	18	Not Mandatory
The ratio of days with good air quality (Air Quality Index (AQI) ≤ 100)	97.5%	Mandatory
NO_x emissions reduction (10,000 metric tonnes)	Comply with national and provincial targets	Not Mandatory
VOCs emissions reduction (10,000 metric tonnes)	Comply with national and provincial targets	Not Mandatory

In Shenzhen's 14th Five-Year Plan (FYP) for climate change mitigation, there are additional indicators related to the impact of air pollution control and GHG mitigation on public health, as outlined in Table 17.[295] As with the FYP for ecology and environmental protection, the selection of these indicators was aligned with targets stipulated in the national 14th FYP.[296] The majority of these indicators serve to assess the efficacy of coordinated measures in managing air pollution and GHG emissions, thus facilitating the evaluation of their consequential effects on public health. The supervision and monitoring of these indicators fall under the purview of the SMBEE and the Shenzhen Municipal Commission of Development and Reform.

TABLE 17 | Indicators with a Connection to Public Health in Shenzhen's 14th FYP for Climate Change and Energy Conservation[297]

Indicator	Target Value by 2025	Mandatory or Not
The percentage of primary electricity[298] in energy consumption	47%	Not Mandatory
The percentage of transportation need fulfilled by green transportation such as railroad, bus, and cycling	81%	Not Mandatory
The Number Of New Energy Vehicles	1 million	Not Mandatory
Forest Coverage Rate	37%	Mandatory
Forest Stock	4.47 million cubic meters	Mandatory

However, according to the "guiding principles" of this plan, it should be noted that these indicators were chosen with the aim of achieving carbon peaking and neutrality, improving the coordinated control of air pollution and GHG emissions, and improving energy and economic

294 Shenzhen Municipal People's Government (2022c).
295 Shenzhen Municipal People's Government (2022a).
296 The National People's Congress of the People's Republic of China (2021).
297 Shenzhen Municipal People's Government (2022a).
298 Primary electricity is nuclear, hydraulic, wind, solar, photovoltaic, and geothermal electricity.

efficiency.[299] As such, public health benefits were not an explicit component of the motivation for Shenzhen's climate change policies.

Finally and notably, Shenzhen's 14th FYP for public health includes some indicators that are related to the impact of air pollution and climate change (Table 18).[300] Since it is scientifically supported that air pollution and climate change can exacerbate chronic diseases and infant mortality, as mentioned in the literature review, these indicators can reflect the effectiveness of Shenzhen's air and climate change policies. Moreover, these indicators were chosen according to the targets in the national 14th FYP.[301] These indicators are monitored by the Shenzhen Municipal Health Commission.

TABLE 18 | Indicators Related to the Impact of Air Pollution and Climate Change in Shenzhen's 14th FYP for Public Health[302]

Indicator	Target Value by 2025	Mandatory or Not
$PM_{2.5}$ annual average concentration (μg/m^3)	18	Not Mandatory
Premature mortality of chronic diseases (including cardiovascular disease, cancer, chronic respiratory disease, etc.)	8.5%	Not mandatory
Infant mortality	2.5%	Not mandatory

Lessons Learned from Case Studies in China

The case studies of Beijing and Shenzhen serve as an example for how some large cities in China are managing their air pollution and GHG emissions, as well as public health impacts. In the absence of explicit public health targets, the case in Beijing and Shenzhen demonstrates the strong political willingness from the top and local governments to tackle air pollution and climate for the sake of improved public health.

Unlike Los Angeles County, in Beijing and Shenzhen, there is a lack of explicit public health targets or indicators in air quality and climate policymaking (such as mortality, morbidity, or hospital admissions) in their Five-Year Plans. Similarly, there is also a lack of targets related to air quality and climate change (such as the concentration of $PM_{2.5}$ and the gross amount of coal consumption) in the Five-Year Plans for public health, especially Beijing's 14th FYP for "healthy Beijing construction." There may be multiple explanations for this. One potential reason for this phenomenon is that there is little cross-departmental coordination between environmental and public health departments when they devise Five-Year Plans and set targets in China. Without adequate collaboration between the environment and public health departments, public health concerns will hardly be incorporated into environmental decision-making, especially the climate change mitigation target-setting process. However, the fulfillment of air and climate targets that do incorporate consideration of public health impacts can help achieve significant public health benefits. For Beijing, Shenzhen, and many other cities like them, more cross-departmental collaboration in target setting may help further facilitate this. Guidance and leadership from higher-level governments are also important to encourage local governments to adopt cross-departmental collaboration.

In addition, local actions can sometimes do little to mitigate air pollution and climate change, as a big proportion of air pollutants in Beijing and Shenzhen come from surrounding regions,[303]

299 Shenzhen Municipal People's Government (2022a).
300 Health Commission of Shenzhen Municipality (2022).
301 The National People's Congress of the People's Republic of China (2021).
302 Health Commission of Shenzhen Municipality (2022).
303 Beijing Municipal Ecology and Environment Bureau (2021); T. Xue et al. (2019).

and climate change is influenced by global GHG emissions, which do not adhere to national boundaries. Given the regional and global features of air pollution and climate change problems, local actions could yield relatively few localized public health benefits, which could also make governments reluctant to include public health indicators as targets. To address these issues, more local research on the public health impact of air pollution and climate change, as well as more in-depth regional collaboration on air pollution and GHG mitigation, is necessary.

Despite gaps in existing policies, some lessons can be learned from the efforts of Beijing and Shenzhen. One lesson is that the environmental governance in many Chinese cities is based on a target-oriented, top-down model, and targets in Five-Year Plans are set based on the national- and provincial-level Five-Year Plans. Therefore, to make public health concerns the motivation of cities' air and climate policies and incorporate public health indicators as targets, national- and provincial-level policies would need to first include such indicators, for local jurisdictions to follow. Raising public awareness about the public health impacts of air pollution and climate change can lead to heightened government awareness of these impacts, which will drive the government to include more public health indicators in policies.

Another lesson is that effectively implementing "coordinated control" is key to Chinese cities' progress in air pollution control and GHG mitigation. Three types of "coordinated control" ("coordinated control" of $PM_{2.5}$ and ozone, "coordinated control" of air pollution and GHGs, and "coordinated control" of pollution among different cities in the same region) should be further implemented in Beijing, Shenzhen, and other cities in China. It can lower the cost of mitigating air pollution and climate change, and yield significant environmental and public health benefits. Examples of "coordinated control" measures include mitigation of NO_x and VOCs, clean manufacturing, industrial structure upgrading, energy consumption structure transformation, and so on.

Finally, carbon markets and trading can help mitigate air pollution and GHG emissions by promoting upgrades in energy and industrial structures. In both Beijing and Shenzhen, the carbon trading mechanism not only lowered the percentage of coal in energy consumption and carbon intensity of power but also promoted the development of industries with low pollution levels and high economic efficiency, which are becoming the new engine for economic development in both cities. The carbon trading mechanisms in both Beijing and Shenzhen are important to the "decoupling" of economic development and carbon emissions, and increase the likelihood of achieving carbon peaking, air quality improvements, and high-quality economic development simultaneously in the future.

7. CONCLUSIONS

Important lessons can be gleaned from considering the public health co-benefits of air pollution and climate actions concurrently. Further, the rapidly evolving nature of the public health and climate nexus highlights the importance of regularly updating policy guidance based on emerging trends in identifying and measuring indicators, as well as the latest science and technological options.

Our report finds that California has a robust portfolio of air quality and climate policy actions that include public health as a direct motive and/or incorporate public health indicators into their efficacy assessments. Key indicators in use include various measures of mortality and morbidity, along with certain socioeconomic indicators. California has demonstrated that public health co-benefits can serve as measurable, quantitative goals within climate and air quality policies. California has made significant progress in incorporating environmental justice considerations into its work, including in vulnerability mapping assessments and measurements of the effectiveness of its policy portfolio on vulnerable communities.

On the other hand, in China, we find that while the co-benefits of addressing air pollution and public health are recognized and integrated into policy development, this is less true for the intersection of public health with climate policy. China meanwhile has excelled at developing highly sophisticated air quality monitoring tools.

Meanwhile, case studies from jurisdictions like Los Angeles, Beijing, and Shenzhen shed insights into real-world examples of the ways in which cities are considering air quality and climate change in tandem, and also the differing extents to which public health is a consideration in their decision-making and policy development processes.

Further, a series of interactive, in-depth expert discussions convened by the California-China Climate Institute revealed several key opportunities for moving forward. Among them include opportunities to take the following actions:

1. **Convene and host exchanges and training opportunities between jurisdictions in California and China to share lessons learned in both directions**. These sessions could entail information-sharing on key indicators in use, methods of tracking and evaluating data, and how data informs policy decision-making processes, as well as technological advances. In particular, there may be specific opportunities for exchange related to green ports and green shipping, given trade routes between the two jurisdictions, and as ports and shipping are important sources of air pollutants and GHGs, thus having a significant impact on public health.
2. **Utilize, replicate, and expand upon the use of technological monitoring and mapping tools.** Tools such as the Environmental Protection Agency's BenMAP tool and the Chinese Environmental Public Health Tracking system provide useful examples of data tools for decision-making in the U.S. and China. Similarly, with respect to vulnerability assessments, in California CalEnviroScreen was cited as a useful framework, and in China the air quality monitoring system also provides a big data platform for public health impact analysis. Both jurisdictions could learn from each other by replicating technological tools, sharing experiences, and even developing tools together.

3. **Further implement "coordinated control" and regional approaches.** The "coordinated control" of GHGs and air pollutants, of various types of air pollutants, and of pollution from cities in the same region has proven to be successful in both California and China. Both jurisdictions should further implement these approaches and learn from each other. International dialogue between specific regions in both jurisdictions, such as the Greater Bay Area in China and the Los Angeles County and Bay Area in California, can promote information sharing and help develop sample regional models for "coordinated control" that could be shared with other regions in both the U.S. and China.

4. **Conduct more localized public health research.** Respondents in China noted that one major challenge for China in incorporating public health indicators in its national and provincial policies is that there is a lack of localized research on the public impact of air pollution and climate change. In other words, the relationship between exposure to air pollution and extreme climate events and public health in specific regions in China is often unclear, making it difficult to assess the public health benefits of air pollution reduction and climate change mitigation. More localized public health research is necessary in China to provide a scientific foundation for sound policymaking.

5. **Embrace and champion the role of multi-stakeholder engagement in driving public health actions.** Respondents in California cited the role of Assembly Bill 617 in driving community co-development of Community Emissions Reductions Plans, citing several communities, including Oakland, that have followed this approach. The communities selected are overburdened with air pollution issues as defined by the State and Air Districts. Several of our respondents indicated that public stakeholder engagement was an important part of improving municipal and other plans, and helped to strengthen and inform plan development in key jurisdictions, like LA. Government agencies highlighted the role that cross-departmental collaboration played in enhancing and strengthening climate policy development. Respondents in China also emphasized how raising awareness about public health problems in the public and government could lead to more health-oriented policies, and therefore, more information dissemination and government-public collaboration would be important.

6. **Prioritize appropriately.** Draw lessons learned and best practices in achieving rapid success in localized air quality in response to pollution concerns from China. Examples from the prioritization of local air quality issues in certain urban contexts in China provide insights into the speed at which results can be achieved when action is prioritized.

7. **Center public health as a lens** for driving climate policy action in China, in addition to air pollution reductions. Examples can be found in California's Scoping Plan which sets the state's climate goals for 2045 and explicitly addresses the health benefits of its policy actions and indicators to measure them by. To take advantage of the public health benefits of air and climate policies, China could include public health indicators in its national targets. Additionally, China could explicitly create opportunities for coordination between public health departments and other departments creating air quality and climate policy, such as the environmental departments and the Development and Reform Commissions in China.

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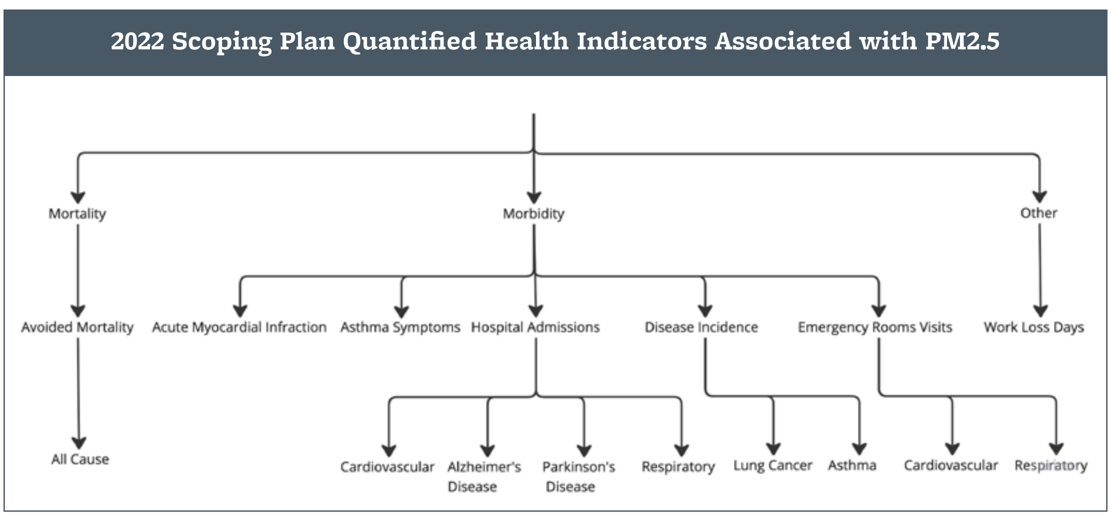
ANNEX I. PUBLIC HEALTH INDICATORS IN CALIFORNIA'S 2022 SCOPING PLAN

Within the Scoping Plan's Appendix G, health co-benefits are analyzed within eight public health arenas: heat impacts, wildfires and smoke impacts, children's health and development, economic security, food security, mobility and physical activity, affordable housing, and urban greening. In each focus area, the analysis compared the expected health benefits between a "no action" and a "take action" approach, as prescribed by the Scoping Plan.

Select health indicators were quantified in Appendix H for modeling analysis used in the AB 32 GHG Inventory Sector modeling. Indicators include: avoided mortality (all causes), hospital admissions, disease incidence, emergency room visits, work loss days, asthma symptoms, and acute myocardial infarction. These health indicators are quantified using the EPA's Benefits Mapping and Analysis Program—Community Edition version 1.5.8 (BenMAP), forecasting the avoided incidence and economic value of certain health effects that result from differences in air pollution concentrations. Each indicator is associated with reductions in exposure to $PM_{2.5}$ and ozone, in accordance with goals set by the scoping plan, and then forecast for both 2035 and 2045 emissions levels. The number of avoided incidences of health outcomes and the value of avoided health incidence are reported in 2021 U.S. dollars. While each health indicator is separately assessed, the total economic value of avoided health incidences is estimated to reach $78 billion in 2035 and $199 billion in 2045. Only focusing on $PM_{2.5}$, total avoided incidence of health endpoints are forecast to reach 1,351,438.8 in 2035 and 2,814,637.4 in 2045.

The expansive list of health indicators included in the plan can be organized into three key categories: mortality, morbidity, and other.



Mortality

As an indicator, mortality is categorized as all-cause and estimated avoided incidence. As recommended by the EPA, the Scoping Plan used a value of statistical life of $8.7 million to quantify mortality risk reduction benefits.

Morbidity

Compared to mortality, morbidity is a broader health indicator. Morbidity includes all diseases, both incident and chronic, within a person or population. The Scoping Plan's main morbidity indicators include disease incidence (or avoided disease incidence), hospitalizations for specific diseases, emergency room visits for specific diseases, and adverse birth outcomes. Disease indicators include incidence of cardiovascular events, breast cancer, colon cancer, diabetes, dementia, lung cancer, respiratory events, depression, and infectious disease. Respiratory events include asthma, both onset and symptoms, and bronchitis symptoms. Hospitalizations and emergency room indicators included cardiovascular, respiratory, and mental health events, and emergency room visits for intestinal infections were also considered. Adverse birth outcomes include preterm birth, low birthweight, and stillbirth.

Children's health was separately considered, with morbidity indicators focusing on mental health, cognitive problems, behavioral health problems, oral health problems, and performance in school.

There were a few additional morbidity indicators related to specific public health areas. Lung function growth and impaired cognitive development are used as indicators for traffic pollution, while iron deficiency in pregnant women and children is specific to food security.

Other Indicators

Income change, work loss days, and GDP are additional indicators of public health. Income change, which includes recent job loss, prolonged unemployment, and shifts to lower paying jobs, is tied to life expectancy, general health status, chronic conditions, and mental health. GDP is also an indicator for life expectancy and health status.

Assessing the state of California regionally, the Scoping Plan found that populations in Southern California will benefit the most from the Scoping Plan because of pre-existing air quality challenges, significant emission sources, and the presence of a large, dense urban population.

In addition to the Scoping Plan, CARB also has developed a Heart and Lung Health Co-benefit Assessment Methodology to measure the heart and lung health impacts of relevant California Climate Investments programs, which are enacted under the Global Warming Solutions Act of 2006.[1] Annex II provides a summary of the indicators that are considered in the 2022 Scoping Plan and the Heart and Lung Health Co-benefit Assessment Methodology.

Beyond CARB, the California Office of Environmental Health Hazard Assessment reports on indicators of climate change in California. The most recent 2022 report observed and tracked the consequences of climate change on public health in California. Human health was one indicator in the report, along with changes in climate, impacts on physical systems, impacts on vegetation and wildlife, and impacts on tribes.[2] The public health indicators measured included:

- heat-related deaths and illnesses,
- occupational heat-related illnesses,
- valley fever (*Coccidioidomycosis*),
- vector-borne diseases, and
- wildfire smoke.[3]

1 California Air Resources Board (2022c).

2 OEHHA (2022).

3 OEHHA (2022).

ANNEX II. INDICATORS CONSIDERED WHEN MEASURING THE IMPACT OF CLIMATE POLICIES ON PUBLIC HEALTH: SCOPING PLAN AND HEART AND LUNG HEALTH CO-BENEFIT ASSESSMENT METHODOLOGY

Policy	Scoping Plan (2022)	Heart and Lung Health Co-benefit Assessment Methodology
Year enacted	**2022**	**2022**
Overarching Public Health Consideration	• Consider the public health benefits that are associated with its different options for achieving California's greenhouse gas and carbon neutrality targets.	• Measure the heart and lung health impacts of relevant California Climate Investments programs.
Specific Public Health Indicators	**Quantitative:** • Rate of all-cause mortality • Number of hospital admissions for asthma, COPD, and all respiratory outcomes • Number of emergency room visits for asthma, all respiratory outcomes, and all cardiac outcomes • Rate of cardiovascular diseases • Rate of colon cancer, breast cancer, and lung cancer • Rate of diabetes • Rate of dementia • Rate of respiratory disease • Rate of depression • Number of traffic incidents • Children o Number of hospital admissions for children's respiratory outcomes o Number of emergency room visits for children's respiratory outcomes o Rate of children's asthma onset o Number of children's asthma symptoms **Qualitative:** • Mortality • Emergency room visits for cardiovascular and respiratory causes and intestinal infections • Hospitalization for cardiovascular and respiratory causes • Preterm birth • Adverse birth outcomes including low birth weight and small for gestational age • Mental illness; mental health; depression • Infectious disease • Chronic illness • Asthma; asthma prevalence • Injuries • Iron deficiency • Life expectancy • Health status • Children o Children's performance in schools o Health o Behavioral problems o Cognitive problems; impaired cognitive development o Iron deficiency o Oral health problems o Lung function growth o Bronchitis symptoms o Adverse birth outcomes, including low birth weight and preterm birth • Climate Vulnerability Metric	**Quantitative:** • Incidence of premature cardiopulmonary mortality • Number of hospitalizations for cardiovascular and respiratory illness • Number of emergency room visits for asthma

ANNEX III. HEALTH INDICATORS FROM SOUTH COAST AIR QUALITY MANAGEMENT DISTRICT'S AIR QUALITY MANAGEMENT PLAN

<table>
<tr><th>Pollutant</th><th>Type of Indicator</th><th>Indicator</th></tr>
<tr><td rowspan="2">Ozone</td><td>Mortality</td><td>Total mortality
Respiratory mortality
Cardiovascular mortality, including metabolic disease mortality</td></tr>
<tr><td>Morbidity</td><td>
Respiratory effects
Short term
Lung function
Respiratory symptoms
Airway responsiveness
Respiratory tract inflammation, injury, and oxidative stress
Respiratory infection and other associated health effects
Respiratory related hospital admissions and Emergency Department (ED) visits for aggregated respiratory-related diseases
Long term
Brain inflammation and morphology
Development of asthma and asthma symptoms
Lung function and development
Development of chronic obstructive pulmonary disease (COPD) and other associated respiratory effects
Respiratory infection and other associated respiratory effects
Allergic responses
Respiratory effects in pregnancy
Respiratory effects in populations with metabolic syndrome
Respiratory mortality

Cardiovascular effects
Short term
Heart failure, impaired heart function, and associated cardiovascular effects
Ischemic heart disease (IHD) and associated cardiovascular effects
Endothelial dysfunction
Cardiac depolarization, repolarization, arrhythmia, and arrest
Blood pressure changes and hypertension
Heart rate (HR) and heart rate variability (HRV)
Coagulation and thrombosis
Systemic inflammation and oxidative stress
Stroke and associated cardiovascular effects
Nonspecific cardiovascular effects
Long term
Atherosclerosis
Heart failure and impaired heart function
Blood pressure changes and hypertension
Heart rate and heart rate variability
Coagulation
Systemic inflammation and oxidative stress
Stroke and associated cardiovascular effects
Other cardiovascular endpoints

Metabolic effects
Short term
Metabolic syndrome
Complications from diabetes
Other indicators of metabolic function
Long term
Metabolic syndrome
Development of diabetes

</td></tr>
</table>

Pollutant	Type of Indicator	Indicator
Ozone	**Mortality**	• Total mortality • Respiratory mortality • Cardiovascular mortality, including metabolic disease mortality
	Morbidity	• **Central nervous system effects** o Short term ■ Cognitive and behavioral effects ■ Neuroendocrine effects ■ Hospital admissions and emergency department visits o Long term ■ Brain inflammation and morphology ■ Effects on cognition, motor activity, and mood ■ Motor function-related effects ■ Neurodevelopmental effects • **Reproductive effects** o Short term ■ Male reproduction ■ Female reproduction o Short term ■ Male reproduction ■ Female reproduction ■ Pregnancy and birth outcomes • **Cancer** o Long term ■ Genotoxicity ■ Cancer incidence, mortality, and survival
$PM_{2.5}$	**Mortality**	• Total mortality • Respiratory mortality • Cardiovascular mortality
	Morbidity	• **Respiratory effects** o Short term ■ Asthma exacerbation ■ Allergy exacerbation ■ Chronic obstructive pulmonary disease (COPD) exacerbation ■ Respiratory infections ■ Combinations of respiratory-related hospital admissions and emergency department visits ■ Respiratory symptoms ■ Lung function ■ Subclinical effects ■ Respiratory tract impacts ■ Respiratory effects in populations with cardiovascular disease o Long term ■ Lung development ■ Development of asthma ■ Development of allergic disease ■ Development of chronic obstructive pulmonary disease (COPD) ■ Respiratory infection ■ Severity of respiratory disease ■ Subclinical effects in healthy populations ■ Respiratory mortality

<table>
<tr><th>Pollutant</th><th>Type of Indicator</th><th>Indicator</th></tr>
<tr><td rowspan="2">$PM_{2.5}$</td><td>Mortality</td><td>

Total mortality
Respiratory mortality
Cardiovascular mortality

</td></tr>
<tr><td>Morbidity</td><td>

Cardiovascular effects

Short term

Emergency department and hospital admissions
Ischemic heart disease, myocardial infarction, heart failure, and heart function
Combinations of cardiovascular-related outcomes

Long term

Cardiovascular heart disease, stroke, and myocardial infarction
Atherosclerosis
Heart failure
Systemic inflammation, coagulation, and endothelial dysfunction

Metabolic effects
Reproductive and developmental effects

Short term
Long term

Male reproduction
Birth outcomes

Nervous system effects
Cancer

Long term

Lung cancer
Liver cancer
Multiple cancers

</td></tr>
<tr><td rowspan="2">PM_{10} $PM_{2.5}$</td><td>Mortality</td><td>

Total mortality
Cardiovascular mortality

</td></tr>
<tr><td>Morbidity</td><td>

Respiratory effects

Short term

Respiratory infection and respiratory-related diseases
Asthma exacerbation

Long term

Cardiovascular effects

Short term

Ischemic heart disease and myocardial infarction
Heart failure and impaired heart function
Ventricular depolarization, repolarization, and arrhythmia
Cerebrovascular disease (CBVD) and stroke
Blood pressure and hypertension
Controlled human exposure studies of heart rate and heart rate variability
Systemic inflammation and oxidative stress
Coagulation
Combinations of cardiovascular-related emergency department visits and hospital admissions

Long term

Nervous system effects

Short term
Long term

Metabolic effects

Long term

Reproductive and developmental effects
Cancer

</td></tr>
</table>

Pollutant	Type of Indicator	Indicator
Ultrafine Particles	**Mortality**	NA
	Morbidity	• **Respiratory effects** o Short term ■ Asthma exacerbation ■ Chronic obstructive pulmonary disease (COPD) exacerbation ■ Respiratory related issues ■ Lung function ■ Respiratory tract oxidative stress ■ Respiratory tract inflammation ■ Respiratory effects in population with COPD ■ Respiratory mortality o Long term • **Cardiovascular effects** o Short term o Long term • **Metabolic effects** o Short term o Long term • **Nervous system effects** o Short term ■ Activation of the sympathetic nervous system and the hypothalamic-pituitary-adrenal stress axis ■ Brain inflammation and oxidative stress ■ Cognitive and behavioral effects o Long term • **Reproductive effects** o Long term • **Cancer** o Long term
Nitrogen dioxide	**Mortality**	• Total mortality • Cardiovascular mortality • Respiratory mortality
	Morbidity	• **Respiratory effects** o Short term o Long term • **Cardiovascular effects** o Short term • **Nervous system effects** • **Other health effects**
Sulfur dioxide	**Mortality**	• Total mortality
	Morbidity	• **Respiratory effects** o Short term ■ Asthma exacerbation ■ Other respiratory effects o Long term • **Cardiovascular effects** o Short term o Long term • **Reproductive and developmental effects** • **Cancer**

ANNEX IV. PUBLIC HEALTH BENEFITS IN LOS ANGELES'S SUSTAINABLE CITY PLAN/GREEN NEW DEAL

Vision and Overarching Targets	Category	Public Health Benefits
Environmental Justice • Improve the raw scores of CalEnviroScreen indicators of Los Angeles communities in the top 10% by an average of 25% by 2025 and 50% by 2035. • Reduce the number of annual childhood asthma-related emergency room visits in Los Angeles's most contaminated neighborhoods to less than 14 per 1,000 children by 2025 and 8 per 1,000 children by 2035.	**Mortality**	• Targets around zero emission vehicles, building electrification, and industrial emissions to save $16 billion from prevented deaths and hospital admissions annually.
	Morbidity	• Targets around zero emission vehicles, building electrification, and industrial emissions will prevent 660 respiratory and cardiovascular hospital admissions annually.
Clean & Healthy Buildings • All new buildings will be net zero carbon by 2030, and 100% of buildings will be net zero carbon by 2050. • Reduce building energy use per square feet for all building types 22% by 2025, 34% by 2035, and 44% by 2050.	**Mortality**	• Zero carbon buildings will prevent 190 premature deaths annually. • Zero carbon buildings will save $1.9 billion from prevented deaths.
	Morbidity	• Zero carbon buildings will prevent 70 respiratory and cardiovascular hospital admissions annually.
Mobility & Public Transit • Increase the percentage of all trips made by walking, biking, micro-mobility/matched rides or transit to at least 35% by 2025, 50% by 2035, and maintain at least 50% by 2050. • Reduce vehicle miles traveled (VMT) per capita by at least 13% by 2025, 39% by 2035, and 45% by 2050. • Ensure Los Angeles is prepared for autonomous vehicles (AV) by the 2028 Olympic and Paralympic Games.	**Morbidity**	• When Angelenos switch from driving to include 15 minutes of walking or biking on their work commute, they will experience • 23% reduced risk of heart disease and stroke. • 15% reduced risk of Type 2 diabetes.
Zero Emission Vehicles • Increase the percentage of electric and zero emission vehicles in the city to 25% by 2025, 80% by 2035, and 100% by 2050. • Electrify 100% of Los Angeles Metro and LADOT buses by 2030. • Reduce port-related GHG emissions by 80% by 2050.	**Mortality**	• Electrifying all vehicles by 2050 will prevent 980 premature deaths annually.
	Morbidity	• Electrifying all vehicles by 2050 will prevent 400 respiratory and cardiovascular hospital admissions annually.
	Other	• Electrifying all vehicles by 2050 will save $9.5 billion from prevented deaths and hospital admissions annually.

Vision and Overarching Targets	Category	Public Health Benefits
Industrial Emissions & Air Quality Monitoring • The City will reach the U.S. EPA 80 ppb ozone attainment standard by 2025 and meet all future compliance dates. • Reduce industrial emissions by 38% by 2035 and 82% by 2050. • Reduce methane leak emissions by 54% by 2035 and 80% by 2050.	**Mortality**	• Reducing industrial emissions 82% by 2050 will prevent 480 premature deaths annually. • Achieving our air quality goals by 2025 will prevent 600 premature deaths annually.
	Morbidity	• Reducing industrial emissions 82% by 2050 will prevent 190 respiratory and cardiovascular hospital admissions annually. • Achieving our air quality goals by 2025 will prevent 250 respiratory and cardiovascular hospital admissions annually.
	Other	• Reducing industrial emissions 82% by 2050 will save $4.7 billion from prevented deaths and hospital admissions annually. • Save $5.8 billion from prevented deaths and hospital admissions annually.