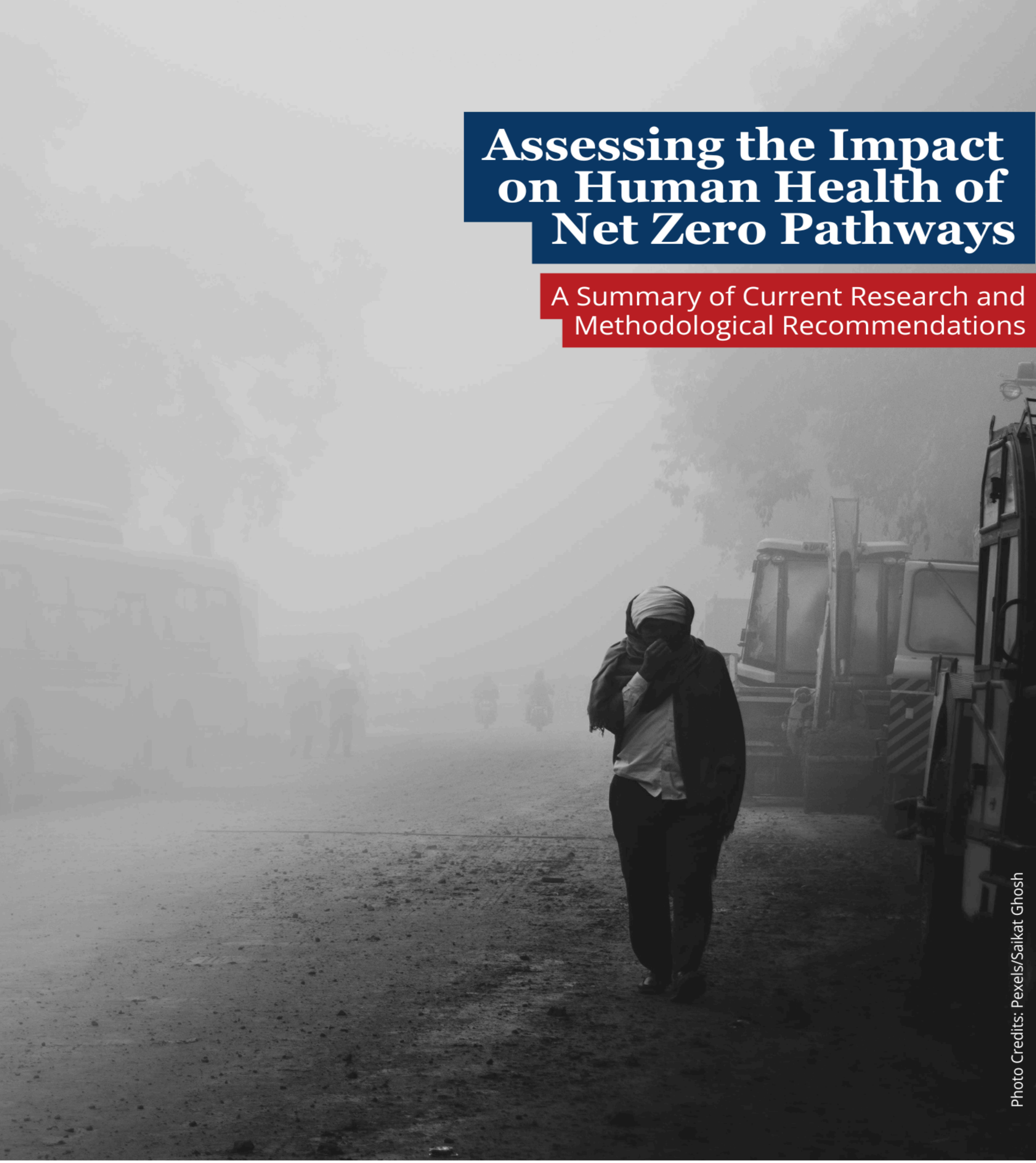
Assessing the Impact on Human Health of Net Zero Pathways

A Summary of Current Research and Methodological Recommendations



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Report Title

Assessing the Impact on Human Health of Net Zero Pathways: A Summary of Current Research and Methodological Recommendations

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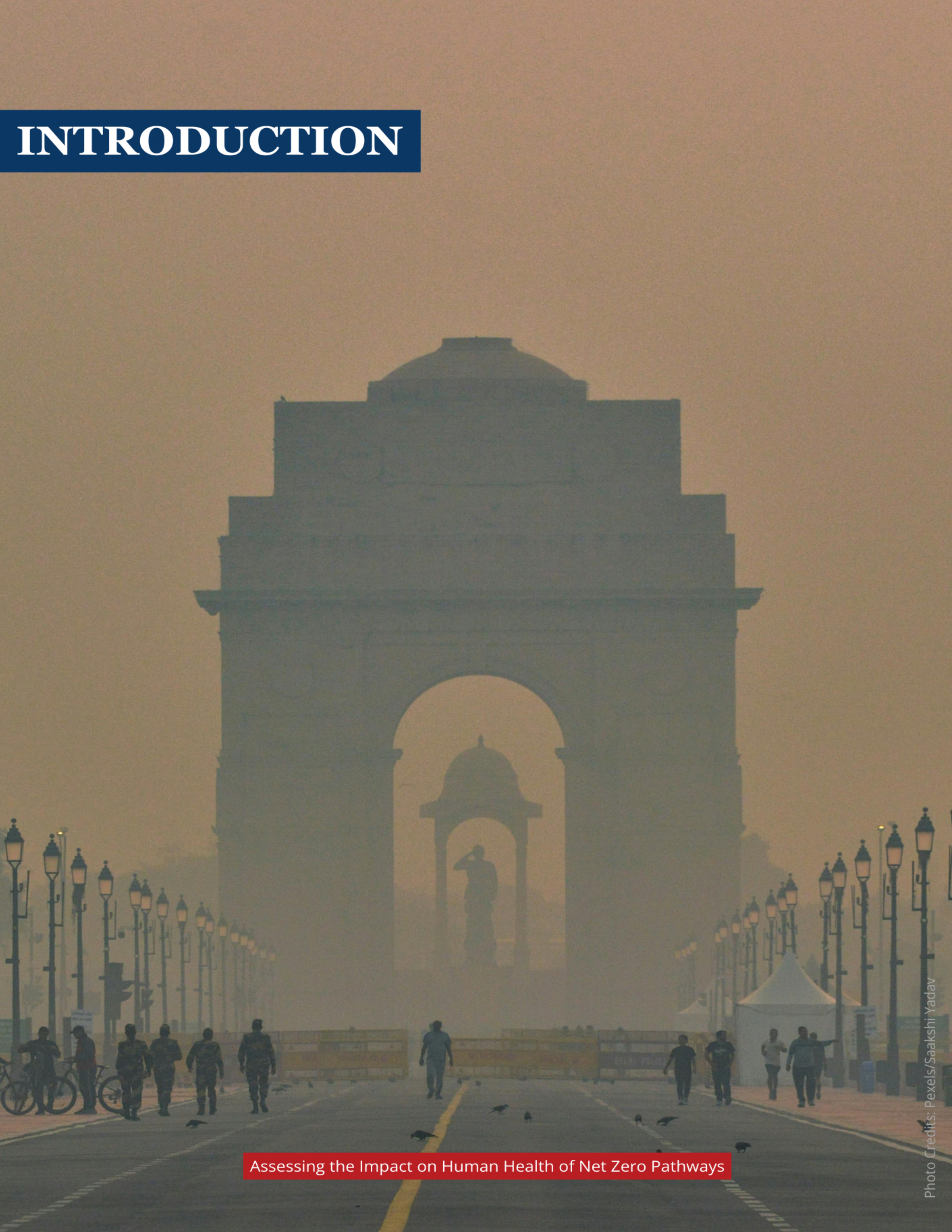
1. Executive Summary

At the 2021 United Nations Climate Change Conference at Glasgow (COP26), India announced its target to achieve net zero emissions by 2070. In addition to the direct benefits resulting from climate action, emissions mitigation policies additionally benefit human health by targeting modifiable environmental and behavioral risks, such as reductions in air pollution from replacing fossil fuels with clean, renewable energy sources. This study explores the diverse health co-benefits resulting from India implementing its net zero goals.

We undertook a scoping review with an exploratory focus to assess the academic and grey literature studying the health impacts of reducing emissions. Research examining the health co-benefits of climate mitigation efforts in India represents a relatively new area of inquiry, growing quickly after the late 2000s. The primary focus of studies in the corpus was on assessing the health co-benefits resulting from reducing ambient air pollution in India, which was linked to severe respiratory and cardiovascular illness, particularly in urban areas and socioeconomically disadvantaged regions in the Indo-Gangetic Plain. The studies note that India stands to gain the greatest health co-benefits globally from climate mitigation efforts, primarily due to high pre-existing pollution levels and severe pollution hotspots, low pollution control and a lack of comprehensive air quality targets as well as relatively low costs of emission reduction, making aggressive climate policies feasible.

Most studies in the corpus use integrated assessment modelling to quantify health co-benefits of various climate mitigation strategies, including reducing air pollution, increasing physical activity, and addressing diet-related emissions. As most studies were conducted by non-Indian institutions, we emphasize the urgent need for localized co-benefits research conducted by Indian researchers and stakeholders to assess the health impacts of current net zero policies.



INTRODUCTION

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2. Introduction

Net zero emissions refers to reducing carbon emissions to a level that can be naturally absorbed or otherwise removed, resulting in no new net emissions being added to the atmosphere. This is important for limiting global warming to no more than 1.5 degree Celsius, as discussed in the Paris Agreement of 2015 (United Nations, n.d.). In line with these discussions, India, recognizing its developmental needs and current lower per capita emissions (about one-third of the global average), has set a target to achieve **net zero by 2070**, as announced at the 2021 United Nations Climate Change Conference at Glasgow (COP26) (Press Information Bureau, 2023).

In addition to the direct benefits resulting from climate action, emissions mitigation policies will benefit human health by targeting modifiable environmental and behavioral risks, such as reductions in air pollution from replacing fossil fuels with clean, renewable energy sources, consumption of sustainable plant-based diets, and the promotion of active travel and use of public transport (Whitmee et al., 2024). These **health co-benefits** (e.g., lower rates of obesity or lung cancer) are additional positive health outcomes of the primary goal of reducing greenhouse gas (GHG) emissions. Co-benefits emphasize the immediate and localized benefits of climate mitigation and therefore have an important role to play in garnering public support and political will for enacting climate policy (Sobhani, 2018). These co-benefits continue to be of increasing importance as data from the *2024 Lancet Countdown on Health and Climate Change* notes that delayed action on the Paris Agreement has resulted in people all around the world facing record-breaking threats to their wellbeing, health, and survival. Indeed, Romanello et al., (2024) note that of the 15 indicators monitoring climate change-related health hazards, exposures, and impacts, ten reached concerning new records in 2023, their most recent year of data.

India experienced record-breaking levels of air pollution in 2024, with urban areas like Delhi reaching never-before-seen levels of ambient air pollution causing unprecedented levels of respiratory illness and hospitalizations (AQI India, 2024). There is thus a great deal of value in better understanding how the published literature discusses the human health impacts of net zero strategies, particularly within the context of India. Reviews on this subject can help to “identify specific health pathways, sectors of activity or levers of decarbonization that are likely to optimize the co-benefits of climate mitigation actions” (Moutet et al. 2024).

Given this background, this report addresses the following research questions (RQs):

> **RQ1)** How can reducing emissions or achieving net zero in India contribute to improved public health outcomes, according to the existing evidence base?
>
> **RQ2)** What approaches have studies used to assess the health impacts of emissions mitigation or net zero strategies in India?

To do so, we conducted a review of the published research literature, for which the methodology is discussed below.

METHODOLOGY

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3. Methodology

Synthesizing the peer-reviewed academic literature and grey literature (e.g., non peer-reviewed reports, white papers) offers useful insights into what ostensibly credible and reliable knowledge has been published on a particular topic, and can enable more robust policy creation and evaluation. While there is a broad range of approaches, tools, and protocols for a knowledge synthesis (such as a systematic review or narrative synthesis), we found a scoping review to be particularly appropriate for addressing the goals of this study because of its exploratory focus. Scoping reviews also help to map the “key concepts that underpin a field of research…clarify working definitions, and/or the conceptual boundaries of a topic” and point to other, more specific questions which can be addressed by more systematic evidence syntheses (Arksey & O’Malley, 2005; Peters et al., 2020). We used criteria and guidelines from the PRISMA extension for scoping reviews (PRISMA-Scr), to identify research questions (see Introduction), identify and select relevant studies in the literature, and summarize, collate, chart, and report the data (Tricco et al., 2018).

3.1 Data Collection

To find relevant studies, we conducted advanced searches on three databases: the Web of Science (WoS), SCOPUS, and PubMed. All three searches were undertaken between September–October 2023 and were supplemented with additional searches using similar keywords on Google Scholar. Each of the three digital databases are often considered the ‘gold standard’ for review research because they are curated, quality-controlled, and cover internationally recognized scholarly journals, books, and proceedings across all disciplines (Chignell & Satterfield, 2023; Pranckutė, 2021). Indeed, the studies in our corpus came from journals across fields such as medicine, energy policy, and environment. The search was limited to English language peer-reviewed and grey literature covering the entire available date range, using four sets of keywords (Table 1), adapted from a similar review on the global health co-benefits literature by Moutet et al. (2024). The first set used the term 'India' in order to focus the search on the geographical area of study. The second set included terms pertaining to 'net zero', 'decarbonization', 'climate change', and 'transition' as these were the most commonly used terms for the interventions of interest to this study. The third set focused on 'health' (and related terms) as these were the specific outcomes being examined. New keywords were added to each column if they showed up repeatedly in the searches (e.g., 'mortality' 'Paris Agreement'), and the searches were repeated including each new keyword. The queries were limited to search keywords appearing in the title, abstract, and keywords of a publication, as these indicate the topics of primary focus within the document.

Table 1: Keyword sets for bibliographic database queries

Set 1	Set 2	Set 3
India*	Net Zero Net-Zero Decarboni* Transition Scenario Carbon Neutrality Paris Agreement Climate Change Act* Climate Change Action* Climate Change Target* Below 2°C Below 1.5°C	Health* Mortality Death*

The queries used to search each bibliographic database were as follows:

WoS: health* OR mortality OR death* (Topic) and "net zero" OR net-zero OR decarboni* OR "transition scenario" OR "carbon neutrality" OR "paris agreement"

OR "climate change act" OR "climate change action*" OR "climate change acts" OR "climate change target*" OR "below 2°C" OR "below 1.5°C " (Topic) and india* (Topic)

SCOPUS: TITLE-ABS-KEY ("health*" OR "mortality OR death*") AND TITLE-ABS-KEY ("net zero" OR "net-zero" OR "decarboni*" OR "transition scenario" OR "carbon neutrality" OR "paris agreement" OR "climate change act" OR "climate change action*" OR "climate change acts" OR "climate change target*" OR "below 2°C" OR "below 1.5°C ") AND TITLE-ABS-KEY ("India*")

PubMed: (health*[Title/Abstract]) OR (mortality[Title/Abstract])) OR (death*[Title/Abstract])) AND ("net zero"[Title/Abstract])) OR (net-zero[Title/Abstract])) OR (decarboni*[Title/Abstract])) OR ("transition scenario"[Title/Abstract])) OR ("carbon neutrality"[Title/Abstract])) OR ("paris agreement"[Title/Abstract])) OR ("climate change act"[Title/Abstract])) OR ("climate change action*"[Title/Abstract])) OR ("climate change acts"[Title/Abstract])) OR ("climate change target*"[Title/Abstract])) OR ("below 2C"[Title/Abstract])) OR ("below 1.5C"[Title/Abstract])) AND (India*[Title/Abstract])

Our searches resulted in a total of 257 initial records, of which 51 were duplicates. After scanning the reference lists of reviews and seminal studies, as well as conducting a final search on Google Scholar with similar keywords, we found a further six records which met our inclusion criteria (English language; focus on health co-benefits; includes India as primary focus or case study). Upon inspecting titles and abstracts, we eliminated 169 records which did not directly discuss the impact of decarbonization or net zero strategies on human health. We did not include studies, for example, which looked at the health impacts of air pollution, as this did not address our focus on the co-benefits of mitigation strategies. A second round of closer reading of the texts led us to eliminate a further 12 studies which did not focus enough on health impacts, but rather on social or economic co-benefits of transition strategies. This left us with a final corpus of 31 studies which addressed the health co-benefits of net zero strategies (Fig. 1).

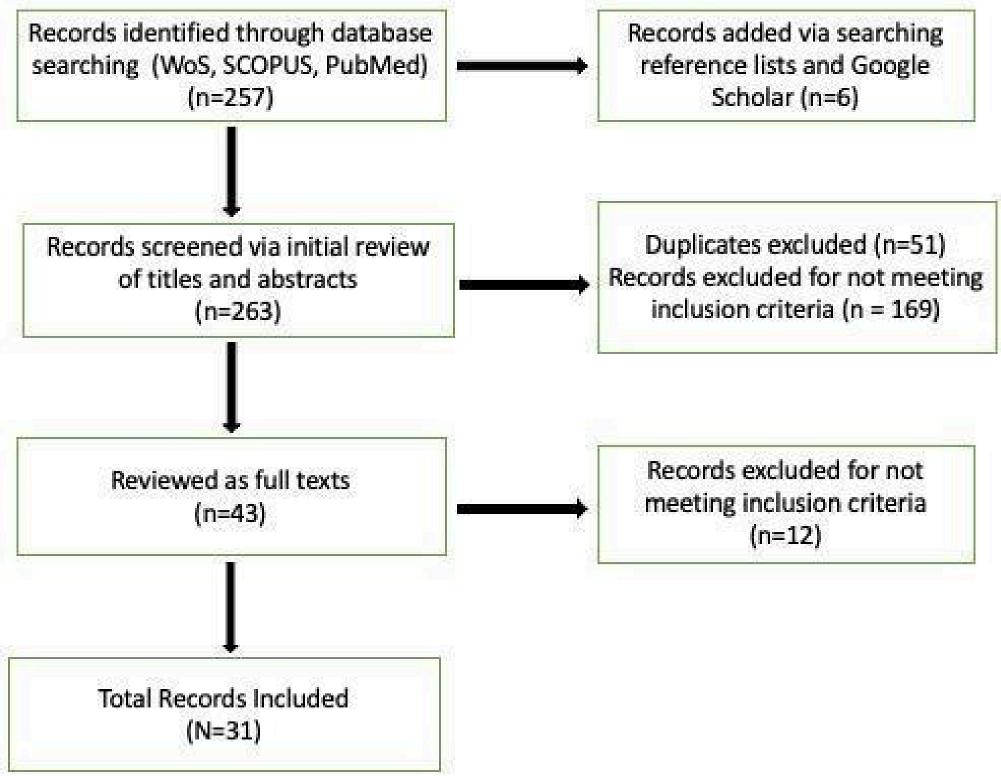


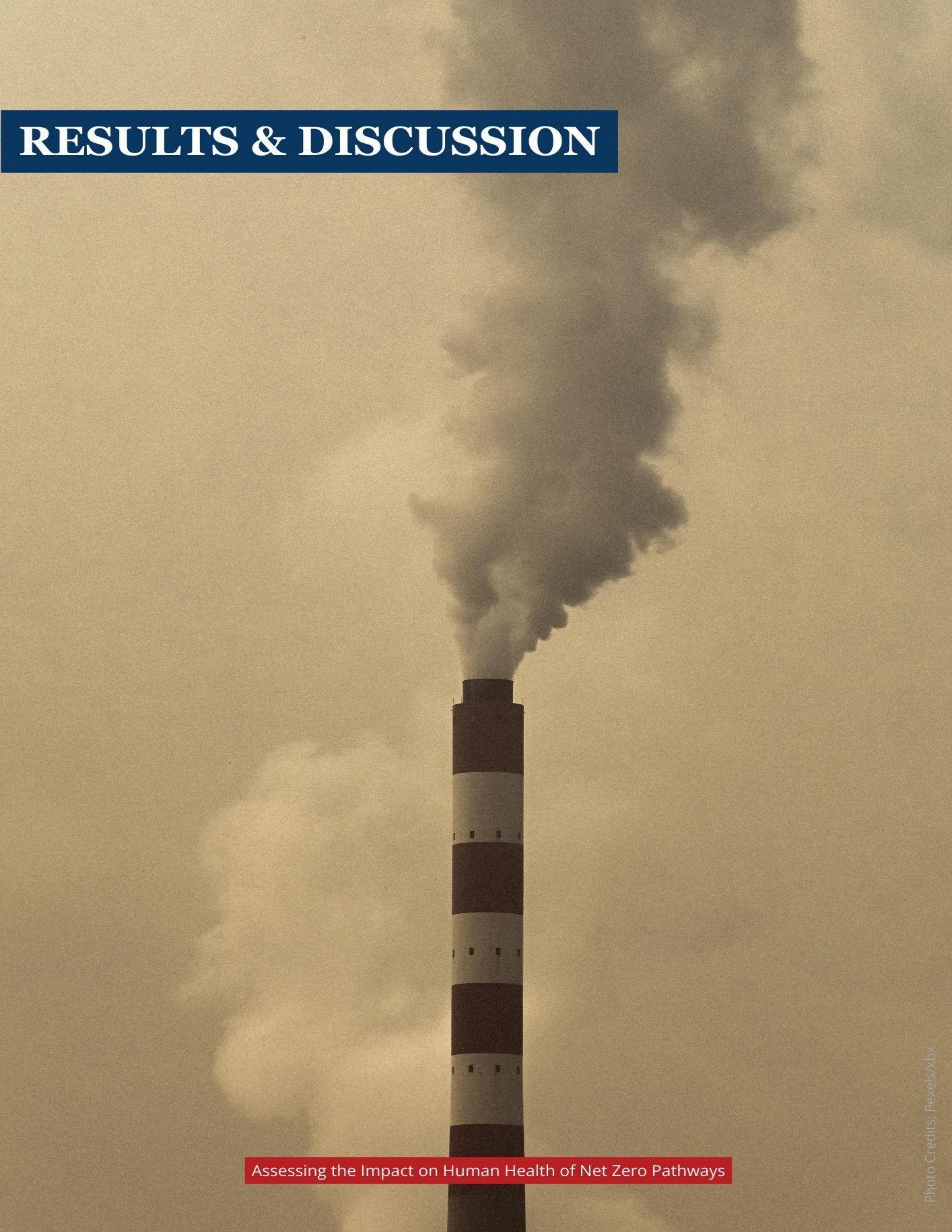
Fig. 1: Record identification, screening, and exclusion

3.2 Charting & Analyzing the Data

We extracted data from our corpus into a predetermined table which was revised iteratively. Variables of interest charted in the table included essential information about each study (e.g., title, date, author names, source name, abstract), features of the study design (e.g., quantitative/qualitative, data collection and analysis), type of health impacts assessment (e.g., exposure-response relationships, health endpoints, interventions), and the study's main findings pertaining to India and, if applicable, globally. Consistent with scoping review guidelines, we did not assess risk of bias and study quality (Tricco et al., 2018). The cleaned bibliographic dataset is available in a separate Excel document (available on request).

After an initial reading of the studies within the corpus, we inductively identified thematic categories pertaining to our RQs (see Introduction). Next, we summarized the discussion of health co-benefits within each document in the corpus, and reported the results based on the themes identified during the charting process visually and as lists, percentages, and frequency counts.

RESULTS & DISCUSSION



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4. Results & Discussion

4.1 Focus on Air Pollution

The health impacts of air pollution are a very well-explored area of our corpus, especially as they pertain to India, and far outpace studies on diet or physical activity (Fig. 2). Nevertheless, despite only a few studies assessing the impacts of diet and physical activity-focused pathways, the benefits arising from changing their patterns have the potential to yield significant health benefits, which in some cases outstrip the benefits from changes to air pollution alone (Hamilton et al., 2021).

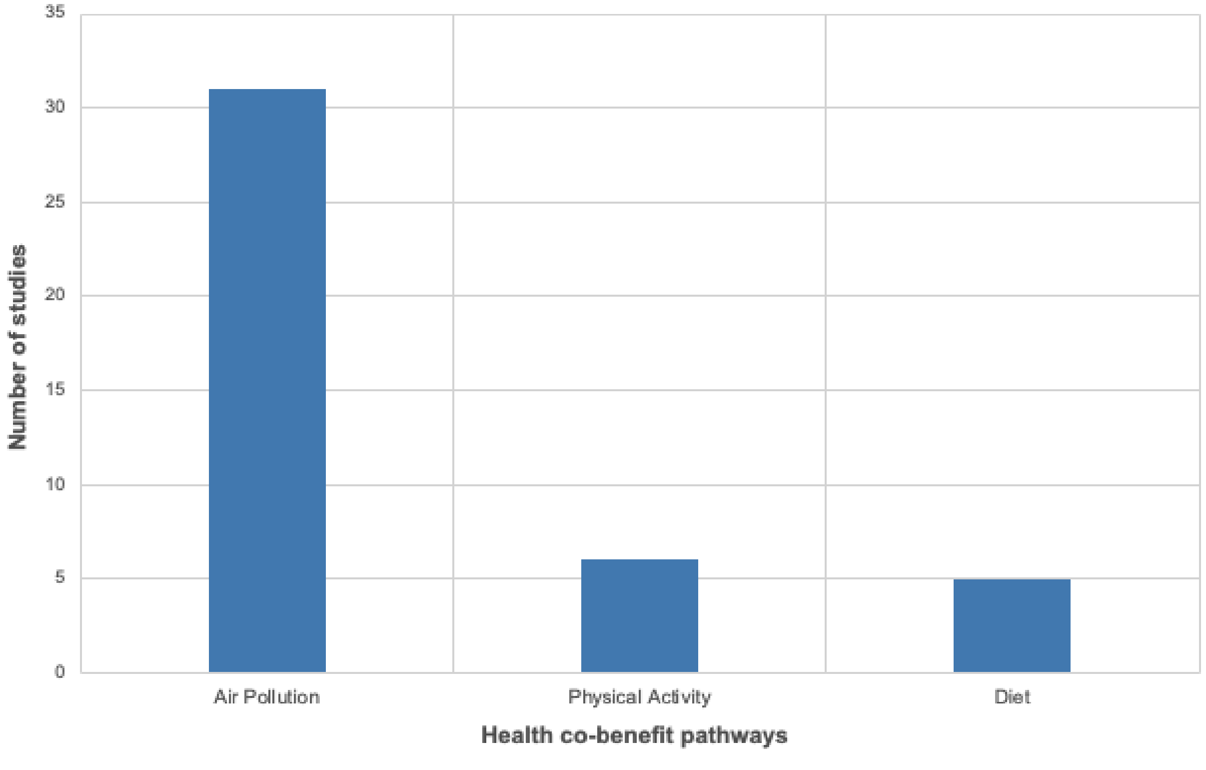

Fig. 2: Summary of health co-benefit pathways examined in the corpus

Several studies highlight that both short- and long-term exposure to ambient air pollution—comprising nitrogen oxides (NOx), sulfur dioxide (SO2), particulate matter (PM), ozone (O3), and carbon monoxide (CO)—are linked to adverse health outcomes, including an increase in premature deaths (Liu et al. 2013; Sehgal et al. 2015; Kesavachandran et al. 2015; Cohen et al. 2017; Haque and Singh 2017). In our corpus, the most studied pollutants include PM2.5 (n=19), CO2 and CO2 equivalents (n=16), NOx (n=11), O3 (n=7), and CO (n=7) (Fig. 3).

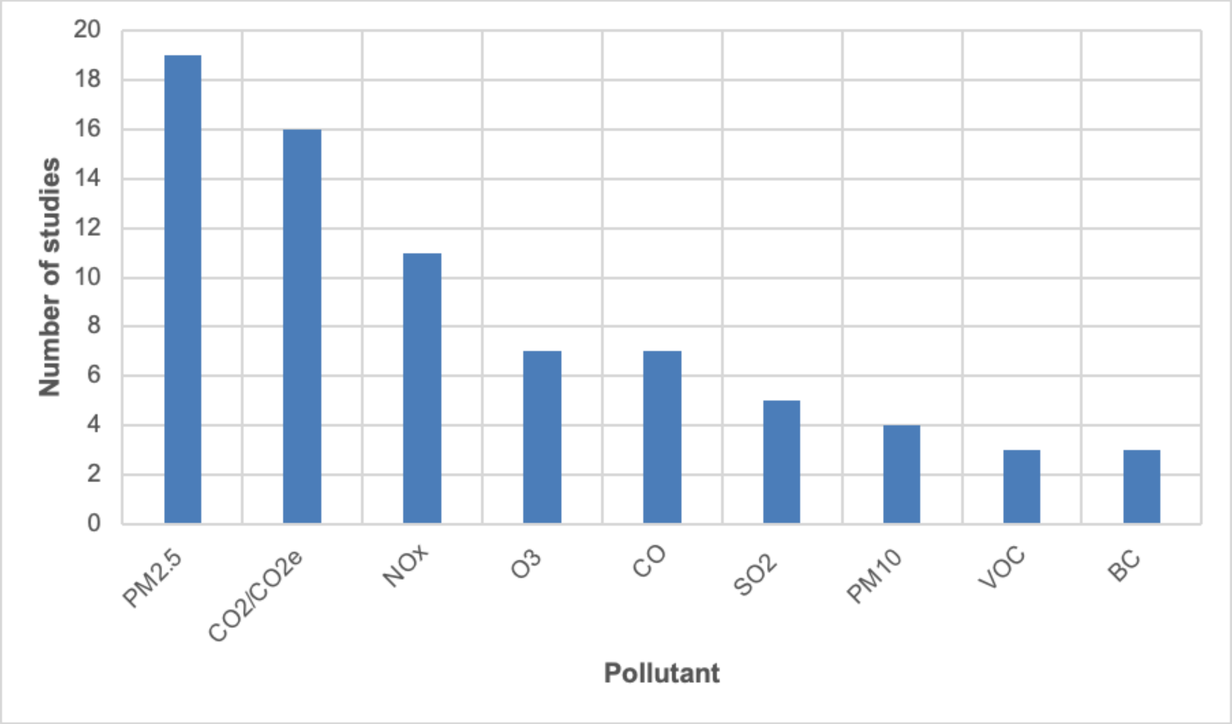

Fig. 3: Summary of pollutants examined in the corpus

Internationally, the United Kingdom's (UK) net zero strategy emphasizes that reducing transport emissions can significantly enhance life expectancy by lowering air pollution levels and promoting active travel (Department of Health and Social Care, 2023; Milner et al., 2023; Woodcock et al., 2009). Data from New Zealand similarly supports that reducing emissions will lead to significant health benefits, such as lower rates of obesity and cardiovascular diseases, through decreased air pollution, increased physical activity, and improved housing conditions (Chambers et al., 2021; Macmillan, 2021).

Given that air pollution is a major planetary health risk, and that India has some of the worst levels globally, there is a considerable impact on deaths, disease burden, and life expectancy across the country (Balakrishnan et al., 2019; Garg, 2011). In fact, air pollution in India is an urgent public health crisis, as 14 cities in the country feature in the world's 20 most polluted cities in terms of PM (e.g., PM2.5) pollution (Rajak & Chattopadhyay, 2020; Sengupta et al., 2022). The northern and eastern parts of the country disproportionately face the burden of PM2.5 mortality, with highly populous states such as Uttar Pradesh, for example, experiencing some of the largest health damages from air pollution, due to reduced air circulation caused by obstruction from the Tibetan Plateau (Peshin et al., 2024; Sengupta et al., 2022). In Delhi, for example, Gurjar et al. (2018) describe a doubling of premature deaths from 1991 to 2010, with short-lived climate pollutants, such as black carbon and O3, contributing significantly to health issues in India. They also report that the largest increase in cardiovascular deaths in Asia is occurring in South Asia, with India being the most affected.

There has been considerable research on the effect of air pollution on health outcomes in the Indian context (though far fewer on the health co-benefits gained from decarbonization), with reviews reporting a sharp incline in the prevalence of non-communicable diseases (NCDs) such as ischemic heart disease, stroke, chronic obstructive pulmonary disease, lower respiratory infections, lung cancer, type 2 diabetes, cataract, low birth weight, and short gestation since the 1990s (Yamamoto et al., 2014; Apte et al., 2015; Balakrishnan et al., 2019; Rajak & Chattopadhyay, 2020; Pandey et al., 2021). Prabhakaran et al. (2020) found that short- and long-term exposure to air pollutants additionally contributed to higher blood pressure and an increased risk of hypertension. In 2017, air pollution was linked to over 1.1 million early deaths in India, which increased sharply to 1.67 million deaths in 2019, making up ~18% of total mortality that year (Kaur &

Pandey, 2020). While there has been a steady reduction in indoor household air pollution since the 1990s (see Fig. 4), increasing ambient PM and ambient O3 pollution were the primary cause of the majority of these deaths (Pandey et al., 2021). Between 1990 and 2016, disability adjusted life-years (DALYs) due to air pollution decreased by 23.6% in India, mainly due to reduction in household air pollution, even while the exposure to ambient air pollution increased by 16.6% during the same period (Dandona et al., 2017). Rao et al., (2021) note transport and indirect emissions associated with household consumption contributed almost twice as much to ambient PM2.5 concentrations as direct emissions from biomass cook stoves.

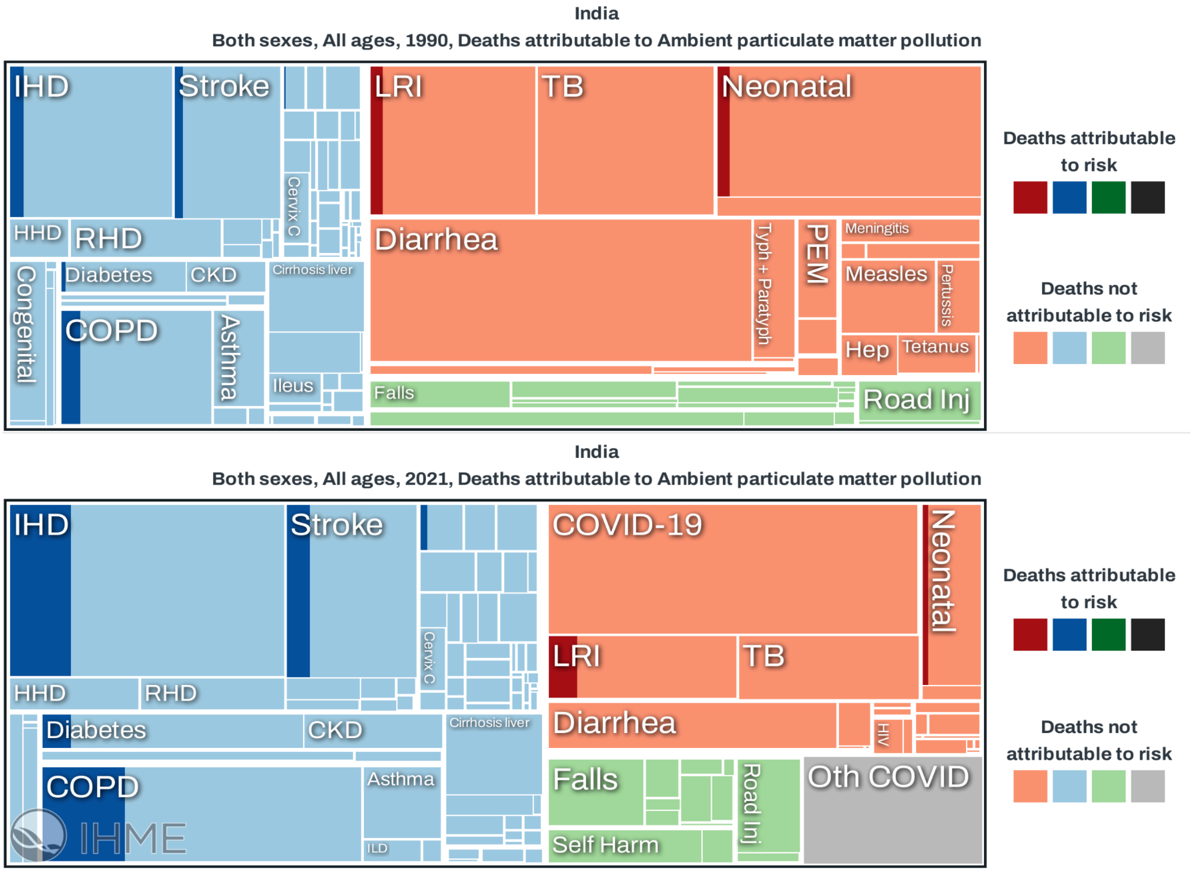

Fig. 4: Comparison of Deaths Attributable to Ambient Particulate Matter Pollution between 1990 and 2021 (Global Burden of Disease Compare Tool)

Rapid planned and unplanned urbanization and a lack of adequate transportation regulation and management has led to congested roads in Indian cities, which in turn increases vehicular emissions by reducing average vehicle speed (Kandlikar & Ramachandran, 2000). In India, the transport sector is responsible for 40% of overall air pollution as of 2023, and road transport alone contributed to 91% of the transport sector's emissions in 2019 (Economic Times, 2023). Between 1990 and 2022, the Indian transport sector's emissions grew at an average annual rate of 1.7%, and the problem of air pollution is further exacerbated by the rapid increase in the use of diesel vehicles (Mittal et al., 2024; Maji et al., 2023). Kaur & Pandey et al. (2021) note that vehicular emissions have been identified as the prevalent source of high NO_2 concentrations in urban areas, and in heavily polluted megacities such as Kolkata and Delhi, over half of all air pollution resulted from motor vehicles. Indeed, vehicular emissions and pollution levels in Indian urban centers were found to exceed World Health Organization (WHO) thresholds by up to 500% and a 50% reduction of land transportation emissions by 2040 would result in 250,000 premature deaths being avoided across the G20 countries (Nawaz et al., 2023), with high-emitter countries such as India and China standing to gain the greatest health benefits from any reduction in air pollution.

4.2 Large Health Co-benefits

Almost all studies in the corpus emphasized that India has the highest rates of premature mortality globally as a result of air pollution, with rates projected to increase significantly in the future under 'business as usual' scenarios and a greater drive towards economic growth. As Stahlke (2023) suggests, this is in part due to a perception that mitigation efforts occur largely at the expense of economic development and must therefore be weighed against national goals such as poverty reduction. Nevertheless, given the size of the population, and India's status as a LMIC, per capita emissions rates remain low (Hamilton et al., 2021).

There is considerable heterogeneity across the studies, which consider different scenarios (e.g., Nationally Determined Contributions of the 2015 Paris Agreement targets), models, pollutants, and emitting sectors (e.g., power generation, transport, household, agriculture). This makes it challenging to meaningfully compare health impacts across studies. However, several studies point out that India would experience some of the greatest health co-benefits from climate mitigation efforts globally given its:

A. Much higher pre-existing levels of ambient and household air pollution making it so that most of the health co-benefits from decarbonization in India would occur domestically, emphasizing the local impact of emission reductions (Nawaz et al., 2023; Sovacool & Monyei, 2021; Markandya et al., 2009). In a review by Whitmee et al. (2024), it was found, for example, that access to clean cookstoves had the greatest estimated median health co-benefits in India, while Dimitrova et al. (2022) and Wilkinson et al. (2009) noted significant benefits to child health, particularly among disadvantaged groups, preventing stunting and lower respiratory infections in millions of children.

B. Presence of some of the worst air pollution hotspots globally, which are projected to significantly worsen under current conditions (Dimitrova et al., 2021; Rauner et al., 2020; Gurjar et al., 2018). Conibear et al. (2018) suggest that a larger percentage of the population in India is exposed to ambient PM2.5 concentrations far exceeding WHO guidelines compared to previous estimates. Following through on enforcing stringent emissions targets would most benefit regions with lower socio-economic development, particularly along the Indo-Gangetic Plain, which currently experience the worst health damages of air pollution (Dimitrova et al., 2021; Vohra et al. 2021).

C. Low levels of pollution control and enforcement currently, with a lack of clear coal emissions or air quality targets and 2015 Nationally Determined

Contributions failing to fully capture potential air quality benefits (Sampedro et al., 2021; Vandyck et al., 2018).

D. Comparatively lower costs of mitigation while accounting for a substantial portion of global co-benefits (Sampedro et al., 2020; Markandya & Wilkinson, 2007). Indeed, Markandya et al. (2018) go so far as to suggest that the costs of reducing GHG emissions in India could be offset by health co-benefits alone, making aggressive climate policies economically viable.

Nevertheless, studies such as Peshin et al. (2024), Sengupta et al. (2022), and Garg (2011) highlight the regional disparities in health co-benefits resulting from interventions such as electric vehicles (EVs); with a continued reliance on coal, eastern states continue to bear the health damages of meeting the energy needs of urban centers, who in turn experience significant benefits from a reduction in transportation emissions. Gupta et al. (2022) revealed EV penetration alone as one of its seven primary levers to reduce the country's emissions by 80%. They note that electrification would likely deliver seven GtCO2e of cumulative abatement from 2022–2070 as it is supported not only by rapid advances in battery technology but explicit support from the government through policy and tax incentives. However, current literature on EVs reveals the many nuances implicit in their production and adoption. Requia et al. (2018) and Gilmore & Patwardhan (2016) note that while EVs may have a role in reducing air pollution and its consequences for human health in India, their positive benefits depend mainly on the type of vehicle and source of energy generation. Nevertheless, Pennington et al. (2024) point out that health co-benefits of the rapid transition to the use of electric vehicles remain largely unexplored, despite an overall positive health impact of the transition to EVs.

4.3 Predominance of Modeling Studies on Air Pollution

There is a predominance of quantitative studies within the corpus (n=26, ~84%), which use integrated assessment modeling (IAM) approaches to link changing emissions levels with health impacts across multiple scenarios. Indeed, the most frequent focus is to link changing emissions levels with current and future concentrations of air pollutants such as PM2.5, which are in turn linked with expected premature mortality rates. IAM not only enables analysis of knowledge across domains such as environmental science, economics, and public health, but allows for the exploration of different net zero policy scenarios in the long term and quantifies their projected impacts on emissions and health. It is thus unsurprising that ~84% (n=26) of sources in our corpus have a quantitative study design.

While the earliest studies within the corpus date back to 2007, ~75% of the sources were published from 2018 onward, indicating that this is a relatively recent area of focus (Fig. 5). It is worth noting that the spike in studies from 2009 points to a *Lancet Series* on public health and climate change, the purpose of which was to argue for a greater recognition of the substantial health benefits of mitigation strategies, which in turn offer the possibility of policy choices that are potentially both more cost effective and socially attractive than are those that address these priorities independently (Haines et al., 2009).

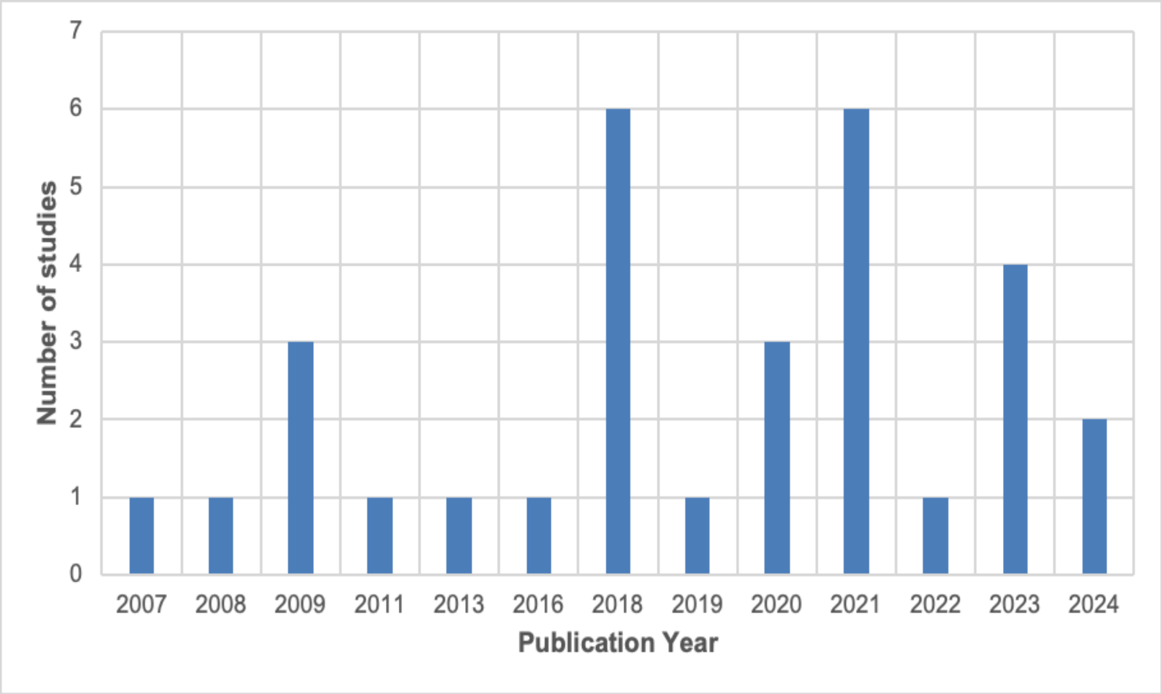

Fig. 5: Summary of source publication years

71% of the studies (n=22) within the corpus were conducted at the global scale, with India featured as one of several case studies. There is a recent, small, yet growing body of literature focusing entirely on the net benefits of specific mitigation strategies for Indian states and regions (n=9) (Peshin et al., 2024; Sengupta et al., 2022), though only 16% (n=5) of the studies in the corpus were based out of Indian institutions. Most global studies use the Nationally Determined Contributions of the 2015 Paris Agreement targets as the basis for their scenarios and modeling. There is thus a pressing need for a co-benefits analysis to be conducted by Indian research institutions, experts, and decision-makers in the fields of environment and public health, in line with the most up to date, government endorsed emissions mitigation strategies for the country.

The most commonly used models in the corpus range across the fields of energy, emissions, heath, and land use. Fig. 6 summarizes the most frequently appearing models across the corpus (in three or more studies) and/or in more recent studies, as the updated methodologies significantly reduce the number of models and inputs necessary to assess health impacts. These models have a range of foci, including computing and projecting emissions levels or human health impacts, which are further described in Table A1 (see Appendix).

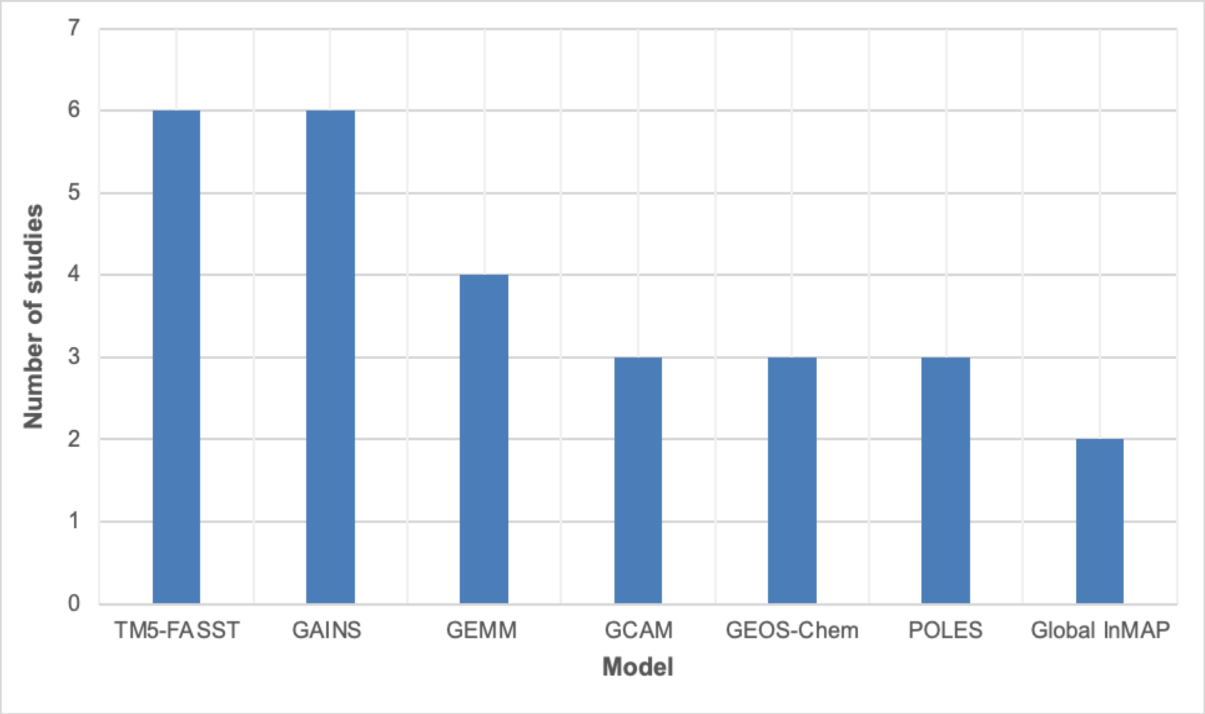

Fig. 6: Summary of models used in three or more studies in the corpus

The most assessed health endpoints across the corpus are premature deaths/mortality (n=24), avoided deaths/mortality (n=6), and economic valuations of morbidity/mortality including value of statistical life (n=9). The integrated exposure-response relationships most frequently used to assess the health impacts of changing emissions levels are those obtained from the Global Burden of Disease (GBD) studies (n=16) and Jerrett et al. (2009) (n=6) to examine the mortality impacts of O3 exposure.

The GBD is the largest and most comprehensive effort to quantify air pollution-related health burdens globally as a result of illnesses such as ischemic heart disease (IHD), Chronic Obstructive Pulmonary Heart Disease (COPD), chronic and acute lower respiratory infections (LRIs) and a range of respiratory diseases (including asthma), lung cancer, stroke, and type II diabetes mellitus (Health Effects Institute, 2020). Within our corpus, we also found that these diseases were some of the most commonly studied health endpoints (Fig. 7).

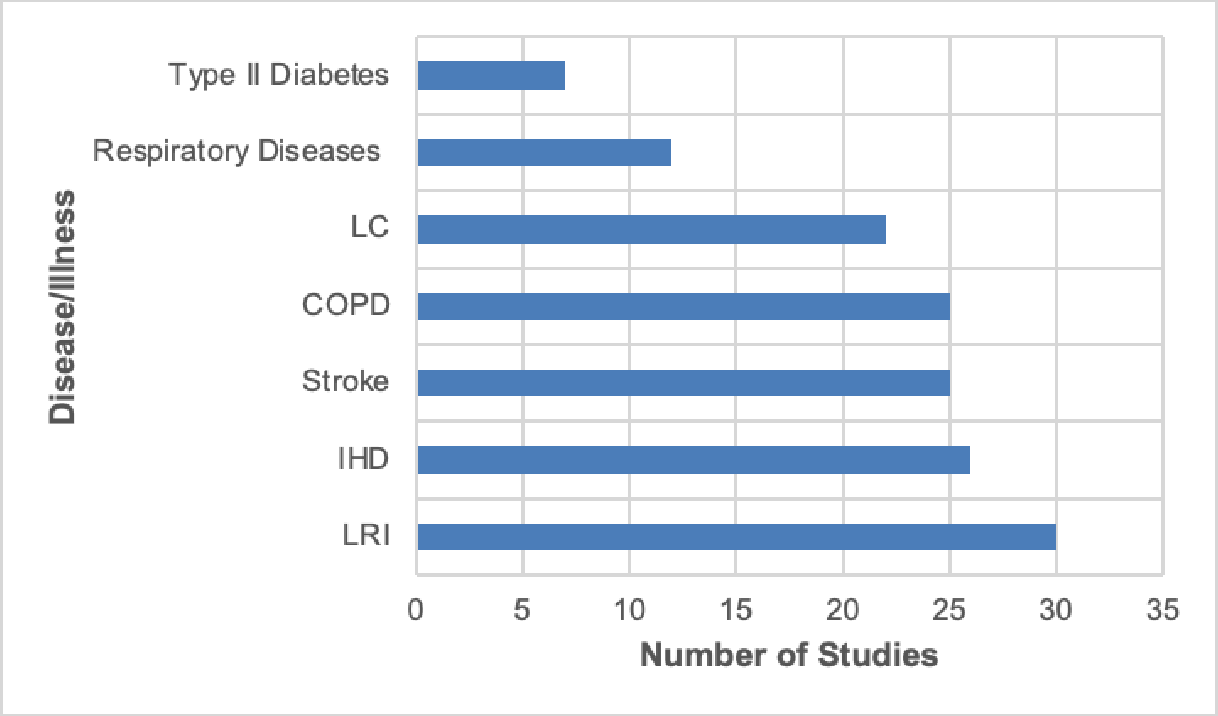

Fig. 7: Summary of diseases/illnesses considered in the corpus

4.4 Diet, Physical Activity & Active Transport

While only ~23% (n=7) of the corpus discussed the health co-benefits associated with an increase in physical activity (i.e., via active transport), this area represents a growing area of interest. Physical inactivity is a major risk factor for NCDs and has been estimated to be responsible for about 5 million premature deaths worldwide annually. In India, this problem is exacerbated by the enormous growth in car ownership in urban areas, far outpacing the growth in population in cities like Delhi (Bhat et al. 2022), as well as rising incomes combined with an inadequate and poorly maintained public transport system which drives people to use personal vehicles. About 70% of vehicles in India are two-wheelers, 25% are cars, jeeps, taxis, and auto-rickshaws, and only 0.7% are public transport vehicles (Verma et al. 2021). A 2024 report on active transport in India notes that a lack of usable sidewalks, poor maintenance, and a prioritization of the flow of car traffic through major urban areas discourages walking as a viable daily commuting option. limiting the access of public transportation, walking, or cycling to a “captive population” (i.e., forced to use them by circumstances and not by choice) (Sports & Society Accelerator, 2024; Tiwari, 2022).

Integrated spatial planning, Ramaswami et al. (2023) note, through designing urban environments that encourage walking, cycling, and public transportation, lowers traffic congestion and air pollution, leading to fewer respiratory diseases and promoting physical activity, which enhances cardiovascular health and overall fitness. Moreover, the co-benefits of enhancing opportunities for greater active and public transport in urban areas is cyclical, because it reduces reliance on private vehicles and the reduction in air pollution is in turn likely to encourage greater use of active transportation options. Given that India suffers from skyrocketing rates of diabetes, obesity, and metabolic disease directly related to physical inactivity and a sedentary lifestyle, a focus on this growing body of literature represents a unique and potentially highly impactful area of intervention.

Studies that focus on diet, by far, represent the smallest percentage of our corpus (n=4), though this may be a reflection of the types of keywords used in our search strategy. The food system sector contributes approximately 30% of global GHG emissions and is projected to increase an additional 30–40% by 2050 due to a rising population and changing consumption patterns if no action is taken (Crippa et al. 2021). Indeed, international authorities on climate and health such as *The Lancet* have begun to acknowledge the immense carbon cost of meat production and consumption globally, with Western nations such as the United States and the UK, as well as China, leading the way in emissions from their food systems (Hamilton et al., 2021; Whitmee et al., 2024). Demand-side consumer behavior and population dietary changes are crucial to any substantial change in this sector, as replacing meat (particularly red meat) with plant-based foods like pulses not only drastically reduces GHG emissions, but also land, water, and energy used in food production (Costa et al. 2022). Milner et al. (2023) who modeled a reduction in meat and dairy consumption as one of the six main pathways to reducing GHG emissions, note that even a modest 35% reduction in red meat consumption with increases in consumption of fruits, vegetables, and legumes, would contribute over 400,000 life-years gained by 2050 and over 2,000,000 life-years gained by 2100 in England and Wales alone.

Moreover, Whitmee at al. (2024) suggest that modeled estimates of the Nationally Determined Contributions of GHG emission reductions in nine countries show that a sustainable pathways scenario would result in an estimated annual reduction by 2040 of about 5.86 million diet-related premature deaths as compared to 1.18 million air pollution-related premature deaths, and 1.15 million premature deaths due to physical inactivity (though there is some overlap across these numbers). While some countries like India, Indonesia, and Nigeria would see little change in deaths avoided by switching to a plant-based diet, heavy meat-consuming nations like Germany, the United States, and China would yield larger co-benefits through dietary shifts, compared to air pollution reduction or active travel (Hamilton et al., 2021; Moutet et al., 2024). In addition to meat consumption, clean cookstoves have been identified as an important and highly effective area of intervention, yielding significant health co-benefits in India in particular, where cooking with solid biofuels remains widespread (see above discussion on household air pollution).

CONCLUSION

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5. Conclusion

The purpose of this report was to review the academic and grey research literature exploring the multifaceted health co-benefits to India of adopting net zero pathways/strategies, and describe the most commonly used methodologies to undertake health co-benefits assessments. This is a subject of growing importance as there is little evidence about the health effects of climate change mitigation interventions in LMICs, which have historically contributed the least to the climate crisis yet are already feeling its most acute health impacts (Wellcome Trust, n.d.). Nevertheless, India's per capita emissions levels are quickly rising, and emphasizing the beneficial externalities of mitigation (particularly the health-related benefits) may indeed enhance the economic case for pursuing aggressive mitigation action imminently (Rogelj et al., 2018).

Our results reveal that reducing India's carbon emissions accrues substantial health benefits including reducing premature mortality, improving cardiovascular and respiratory health, and enhancing quality of life. The literature indicates that India stands to gain greatly from aligning its climate action strategies with public health goals because its most critical health challenges today pertain to the sharp increase in NCDs caused by ambient air pollution and physical inactivity. In addition, several studies note that mitigation costs are likely to be low given the relatively few controls on air pollution, and domestic co-benefits very high as Indian cities are already experiencing some of the worst air pollution globally. Indeed, in India and other LMICs, the health co-benefits of aggressive climate mitigation efforts are understood to be beneficial precisely because their resulting health gains would likely offset a substantial proportion of mitigation costs.

Nevertheless, it is worth noting that most of the studies within the corpus (84%) were produced by non-Indian institutions and often use the Nationally Determined Contributions of the 2015 Paris Agreement targets to delineate intervention scenarios. Several studies emphasize the need for localized and sector-specific studies, especially for regions and populations which are disproportionately affected by environmental degradation. Given the recent air pollution crisis in Delhi and the rapid increase in NCDs such as heart disease, type-II diabetes, cancer, and LRIs in urban centers throughout the country, it is clear that there is a pressing need for research institutions in India to work alongside government sectors to develop a more up-to-date and holistic model examining the health co-benefits of reducing GHG emissions. This modeling process should be transdisciplinary, context and policy-relevant, and developed through stakeholder engagement and buy-in.

6. References

Apte, J. S., Marshall, J. D., Cohen, A. J., & Brauer, M. (2015). Addressing Global Mortality from Ambient PM2.5. *Environmental Science & Technology*, *49*(13), 8057–8066.

Arksey, H., & O'Malley, L. (2005). Scoping studies: Towards a methodological framework. *International Journal of Social Research Methodology*, *8*(1), 19–32.

AQI India. (2024). *Delhi AQI becomes the most polluted ever in history*. Retrieved December 13, 2024, from https://www.aqi.in/blog/delhi-aqi-becomes-the-most-polluted-ever-in-history/

Balakrishnan, K., Dey, S., Gupta, T., Dhaliwal, R. S., Brauer, M., Cohen, A. J., Stanaway, J. D., Beig, G., Joshi, T. K., Aggarwal, A. N., Sabde, Y., Sadhu, H., Frostad, J., Causey, K., Godwin, W., Shukla, D. K., Kumar, G. A., Varghese, C. M., Muraleedharan, P., … Dandona, L. (2019). The impact of air pollution on deaths, disease burden, and life expectancy across the states of India: The Global Burden of Disease Study 2017. *The Lancet Planetary Health*, *3*(1), e26–e39.

Bhat, T. H., Farzaneh, H., & Toosty, N. T. (2022). Co-benefit assessment of active transportation in Delhi, estimating the willingness to use nonmotorized mode and near-roadway-avoided PM2. 5 exposure. *International Journal of Environmental Research and Public Health*, *19*(22), 14974.

Burnett, R. T., Pope, C. A., Ezzati, M., Olives, C., Lim, S. S., Mehta, S., Shin, H. H., Singh, G., Hubbell, B., Brauer, M., Anderson, H. R., Smith, K. R., Balmes, J. R., Bruce, N. G., Kan, H., Laden, F., Prüss-Ustün, A., Turner, M. C., Gapstur, S. M., … Cohen, A. (2014). An Integrated Risk Function for Estimating the Global Burden of Disease Attributable to Ambient Fine Particulate Matter Exposure. *Environmental Health Perspectives*, *122*(4), 397–403.

Chambers, T., Hales, S., Shaw, C., Baker, M., Ball, J., Cleghorn, C., & Wilson, N. (2021). New Zealand's Climate Change Commission report: The critical need to address the missing health co-benefits of reducing emissions. *The New Zealand Medical Journal (Online)*, *134*(1542), 109–118.

Chignell, S. M., & Satterfield, T. (2023). Seeing beyond the frames we inherit: A challenge to tenacious conservation narratives. *People and Nature*, *5*(6), 2107–2123.

Chowdhury, S., Dey, S., & Smith, K. R. (2018). Ambient PM2. 5 exposure and expected premature mortality to 2100 in India under climate change scenarios. *Nature Communications*, *9*(1), 318.

Cohen, A. J., Brauer, M., Burnett, R., Anderson, H. R., Frostad, J., Estep, K., Balakrishnan, K., Brunekreef, B., Dandona, L., Dandona, R., Feigin, V., Freedman, G., Hubbell, B., Jobling, A., Kan, H., Knibbs, L., Liu, Y., Martin, R., Morawska, L., … Forouzanfar, M. H. (2017). Estimates and 25-year trends of the global burden of disease attributable to ambient air pollution: An analysis of data from the Global Burden of Diseases Study 2015. *The Lancet*, *389*(10082), 1907–1918.

Conibear, L., Butt, E. W., Knote, C., Arnold, S. R., & Spracklen, D. V. (2018). Stringent emission control policies can provide large improvements in air quality and public health in India. *GeoHealth*, *2*(7), 196-211.

Costa Jr, C., Wollenberg, E., Benitez, M., Newman, R., Gardner, N., & Bellone, F. (2022). Roadmap for achieving net-zero emissions in global food systems by 2050. *Scientific Reports*, *12*(1), 15064.

Crippa, M., Solazzo, E., Guizzardi, D., Monforti-Ferrario, F., Tubiello, F. N., & Leip, A. (2021). Food systems are responsible for a third of global anthropogenic GHG emissions. *Nature Food*, *2*(3), 198–209.

Dandona, L., Dandona, R., Kumar, G. A., Shukla, D. K., Paul, V. K., Balakrishnan, K., Prabhakaran, D., Tandon, N., Salvi, S., Dash, A. P., Nandakumar, A., Patel, V., Agarwal, S. K., Gupta, P. C., Dhaliwal, R. S., Mathur, P., Laxmaiah, A., Dhillon, P. K., Dey, S., … Swaminathan, S. (2017). Nations within a nation: Variations in epidemiological transition across the states of India, 1990–2016 in the Global Burden of Disease Study. *The Lancet*, *390*(10111), 2437–2460.

Department of Health and Social Care. (2023). *Health effects of climate change (HECC) in the UK: 2023 report. Chapter 14. Net zero: Health impacts of policies to reduce greenhouse gas emissions*. https://assets.publishing.service.gov.uk/media/657060b7739135000db03bcb/HECC-report-2023-chapter-14-net-zero.pdf

Dimitrova, A., Marois, G., Kiesewetter, G., Samir, K. C., Rafaj, P., & Tonne, C. (2021). Health impacts of fine particles under climate change mitigation, air quality control, and demographic change in India. *Environmental Research Letters*, *16*(5), 054025.

Dimitrova, A., Marois, G., Kiesewetter, G., Rafaj, P., Pachauri, S., Samir, K. C., … & Tonne, C. (2022). Projecting the impact of air pollution on child stunting in India—synergies and trade-offs between climate change mitigation, ambient air quality control, and clean cooking access. *Environmental Research Letters*, *17*(10), 104004.

Economic Times. (2023, June 10). *Transport sector accounts for 40 per cent of air pollution, need to develop greener fuels: Gadkari*. The Economic Times. https://economictimes.indiatimes.com/industry/renewables/transport-sector-accounts-for-40-per-cent-of-air-pollution-need-to-develop-greener-fuels-gadkari/articleshow/100509892.cms

Garg, A. (2011). Pro-equity effects of ancillary benefits of climate change policies: a case study of human health impacts of outdoor air pollution in New Delhi. *World Development*, *39*(6), 1002-1025.

Gilmore, E. A., & Patwardhan, A. (2016). Passenger vehicles that minimize the costs of ownership and environmental damages in the Indian market. *Applied Energy*, *184*, 863-872.

Gupta, R., Malik, D., Sanke, S., & Unni, N. (2022). *Decarbonising India: Charting a pathway for sustainable growth*. McKinsey Sustainability. https://www.mckinsey.com/capabilities/sustainability/our-insights/decarbonising-india-charting-a-pathway-for-sustainable-growth

Gurjar, B. R., Ohara, T., Khare, M., Kulshrestha, P., Tyagi, V., & Nagpure, A. S. (2018). South Asian Perspective: A Case of Urban Air Pollution and Potential for Climate Co-benefits in India. In M. Sethi & J. A. Puppim de Oliveira (Eds.), *Mainstreaming Climate Co-Benefits in Indian Cities: Post-Habitat III Innovations and Reforms* (pp. 77–98). Springer.

Haines, A., McMichael, A. J., Smith, K. R., Roberts, I., Woodcock, J., Markandya, A., Armstrong, B. G., Campbell-Lendrum, D., Dangour, A. D., Davies, M., Bruce, N., Tonne, C., Barrett, M., & Wilkinson, P. (2009). Public health benefits of strategies to reduce greenhouse-gas emissions: Overview and implications for policy makers. *The Lancet*, *374*(9707), 2104–2114.

Hamilton, I., Kennard, H., McGushin, A., Höglund-Isaksson, L., Kiesewetter, G., Lott, M., ... & Watts, N. (2021). The public health implications of the Paris Agreement: a modelling study. *The Lancet Planetary Health*, *5*(2), e74-e83.

Haque, M. S., & Singh, R. B. (2017). Air Pollution and Human Health in Kolkata, India: A Case Study. *Climate*, *5*(4), Article 4.

Health Effects Institute. (2020). *State of global air 2020*. Special Report. Health Effects Institute. https://www.healthdata.org/research-analysis/library/state-global-air-2020

Jerrett, M., Burnett, R. T., Pope, C. A., Ito, K., Thurston, G., Krewski, D., Shi, Y., Calle, E., & Thun, M. (2009). Long-Term Ozone Exposure and Mortality. *New England Journal of Medicine*, *360*(11), 1085–1095.

Kaur, R., & Pandey, P. (2021). Air Pollution, Climate Change, and Human Health in Indian Cities: A Brief Review. *Frontiers in Sustainable Cities*, *3*.

Kandlikar, M., & Ramachandran, G. (2000). The causes and consequences of particulate air pollution in urban India: A Synthesis of the Science. *Annual Review of Environment and Resources*, *25*(Volume 25, 2000), 629–684.

Kesavachandran, C. N., Kamal, R., Bihari, V., Pathak, M. K., & Singh, A. (2015). Particulate matter in ambient air and its association with alterations in lung functions and respiratory health problems among outdoor exercisers in National Capital Region, India. *Atmospheric Pollution Research*, *6*(4), 618–625.

Liu, C., Ying, Z., Harkema, J., Sun, Q., & Rajagopalan, S. (2013). Epidemiological and Experimental Links between Air Pollution and Type 2 Diabetes. *Toxicologic Pathology*, *41*(2), 361–373.

Macmillan, A. (2021). The Climate Change Act will now shape the nation's health: An assessment of the first policy recommendations to reach our zero carbon target. *The New Zealand Medical Journal (Online)*, *134*(1530), 8–11.

Maji, S., Ahmed, S., Kaur-Sidhu, M., Mor, S., & Ravindra, K. (2023). Health Risks of Major Air Pollutants, their Drivers and Mitigation Strategies: A Review. *Air, Soil and Water Research*, *16*, 1-12.

Markandya, A., & Wilkinson, P. (2007). Electricity generation and health. *The Lancet*, *370*(9591), 979-990.

Markandya, A., Armstrong, B. G., Hales, S., Chiabai, A., Criqui, P., Mima, S., ... & Wilkinson, P. (2009). Public health benefits of strategies to reduce greenhouse-gas emissions: low-carbon electricity generation. *The Lancet*, *374*(9706), 2006-2015.

Markandya, A., Sampedro, J., Smith, S. J., Van Dingenen, R., Pizarro-Irizar, C., Arto, I., & González-Eguino, M. (2018). Health co-benefits from air pollution and mitigation costs of the Paris Agreement: a modelling study. *The Lancet Planetary Health*, *2*(3), e126-e133.

Milner, J., Turner, G., Ibbetson, A., Colombo, P. E., Green, R., Dangour, A. D., Haines, A., & Wilkinson, P. (2023). Impact on mortality of pathways to net zero greenhouse gas emissions in England and Wales: A multisectoral modelling study. *The Lancet Planetary Health*, *7*(2), e128–e136.

Mittal, G., Garg, A., & Pareek, K. (2024). A review of the technologies, challenges and policies implications of electric vehicles and their future development in India. *Energy Storage*, *6*(1), e562.

Moutet, L., Bernard, P., Green, R., Milner, J., Haines, A., Slama, R., ... & Jean, K. (2024). The public health co-benefits of strategies consistent with net-zero emissions: a systematic review of quantitative studies. *medRxiv*, 2024-08.

Nawaz, M. O., Henze, D. K., Anenberg, S. C., Braun, C., Miller, J., & Pronk, E. (2023). A Source Apportionment and Emission Scenario Assessment of PM2. 5-and O3-Related Health Impacts in G20 Countries. *GeoHealth*, *7*(1), e2022GH000713.

Pandey, A., Brauer, M., Cropper, M. L., Balakrishnan, K., Mathur, P., Dey, S., Turkgulu, B., Kumar, G. A., Khare, M., & Beig, G. (2021). Health and economic impact of air pollution in the states of India: The Global Burden of Disease Study 2019. *The Lancet Planetary Health*, *5*(1), e25–e38.

Pennington, A. F., Cornwell, C. R., Sircar, K. D., & Mirabelli, M. C. (2024). Electric vehicles and health: A scoping review. *Environmental Research*, *251*, 118697.

Peshin, T., Sengupta, S., Thakrar, S. K., Singh, K., Hill, J., Apte, J. S., ... & Azevedo, I. M. (2024). Air quality, health, and equity impacts of vehicle electrification in India. *Environmental Research Letters*, *19*(2), 024015.

Peters, M., Godfrey, C., McInerney, P., Munn, Z., Tricco, A., & Khalil, H. (2020). Chapter 11: Scoping Reviews. In E. Aromataris & Z. Munn (Eds.), *JBI Manual for Evidence Synthesis*. JBI.

Prabhakaran, D., Mandal, S., Krishna, B., Magsumbol, M., Singh, K., Tandon, N., Venkat Narayan, K. M., Shivashankar, R., Kondal, D., Ali, M. K., Srinath Reddy, K., Schwartz, J. D., & GeoHealth Hub Study investigators, COE-CARRS Study investigators. (2020). Exposure to Particulate Matter Is Associated With Elevated Blood Pressure and Incident Hypertension in Urban India. *Hypertension*, *76*(4), 1289–1298.

Pranckutė, R. (2021). Web of Science (WoS) and Scopus: The Titans of Bibliographic Information in Today's Academic World. *Publications*, *9*(1), Article 1. Press Information Bureau. (2023, August 3). *Net zero emissions target*. Ministry of Environment, Forest and Climate Change. Government of India. https://pib.gov.in/PressReleaseIframePage.aspx?PRID=1945472

Rajak, R., & Chattopadhyay, A. (2020). Short and Long Term Exposure to Ambient Air Pollution and Impact on Health in India: A Systematic Review. *International Journal of Environmental Health Research*, *30*(6), 593–617.

Ramaswami, A., Pandey, B., Li, Q., Das, K., & Nagpure, A. (2023). Toward Zero-Carbon Urban Transitions with Health, Climate Resilience, and Equity Co-Benefits: Assessing Nexus Linkages. *Annual Review of Environment and Resources*, *48*(1), 81-121.

Rao, N. D., Kiesewetter, G., Min, J., Pachauri, S., & Wagner, F. (2021). Household contributions to and impacts from air pollution in India. *Nature Sustainability*, *4*(10), 859-867.

Rauner, S., Hilaire, J., Klein, D., Strefler, J., & Luderer, G. (2020). Air quality co-benefits of ratcheting up the NDCs. *Climatic Change*, *163*, 1481-1500.

Requia, W. J., Mohamed, M., Higgins, C. D., Arain, A., & Ferguson, M. (2018). How clean are electric vehicles? Evidence-based review of the effects of electric mobility on air pollutants, greenhouse gas emissions and human health. *Atmospheric Environment*, *185*, 64–77.

Rogelj, J., Shindell, D., Jiang, K., Fifita, S., Forster, P., Ginzburg, V., ... & Zickfeld, K. (2018). Mitigation pathways compatible with 1.5 C in the context of sustainable development. In *Global Warming of 1.5 C* (pp. 93-174). Intergovernmental Panel on Climate Change.

Sampedro, J., Smith, S. J., Arto, I., González-Eguino, M., Markandya, A., Mulvaney, K. M., ... & Van Dingenen, R. (2020). Health co-benefits and mitigation costs as per the Paris Agreement under different technological pathways for energy supply. *Environment International*, *136*, 105513.

Sampedro, J., Cui, R. Y., McJeon, H., Smith, S. J., Hultman, N., He, L., ... & Cazcarro, I. (2021). Quantifying the reductions in mortality from air-pollution by cancelling new coal power plants. *Energy and Climate Change*, *2*, 100023.

Sehgal, M., Suresh, R., Sharma, V. P., & Gautam, S. K. (2015). Assessment of outdoor workers' exposure to air pollution in Delhi (India). *International Journal of Environmental Studies*, *72*(1), 99–116.

Sengupta, S., Thakrar, S. K., Singh, K., Tongia, R., Hill, J. D., Azevedo, I. M., & Adams, P. J. (2022). Inequality in air pollution mortality from power generation in India. *Environmental Research Letters*, *18*(1), 014005.

Sobhani, N. (2018). The Role of Co-Benefits: Rethinking The Costs and Benefits of Climate Change Mitigation. *Niskanen Center*. https://www.niskanencenter.org/therole-of-co-benefits-rethinking-the-costs-and-benefits-of-climate-change-mitigation/

Sovacool, B. K., & Monyei, C. G. (2021). Positive externalities of decarbonization: quantifying the full potential of avoided deaths and displaced carbon emissions from renewable energy and nuclear power. *Environmental Science & Technology*, *55*(8), 5258-5271.

Sports & Society Accelerator. (2024). Active Transit for India. *Sports & Society Accelerator*. https://sports-society.org/issue-briefs/active-transit-for-india

Stahlke, T. (2023). Climate policy and the concept of co-benefits in India. *Journal of Social and Economic Development*, *25*(1), 86–102.

Tiwari, G. (2022, July 26). Walking in Indian cities – A daily agony for millions. *The Hindu Centre*. https://www.thehinducentre.com/the-arena/current-issues/walking-in-indian-cities-a-daily-agony-for-millions/article65551959.ece

Tricco, A. C., Lillie, E., Zarin, W., O'Brien, K. K., Colquhoun, H., Levac, D., Moher, D., Peters, M. D. J., Horsley, T., Weeks, L., Hempel, S., Akl, E. A., Chang, C., McGowan, J., Stewart, L., Hartling, L., Aldcroft, A., Wilson, M. G., Garritty, C., … Straus, S. E. (2018). PRISMA Extension for Scoping Reviews (PRISMA-ScR): Checklist and Explanation. *Annals of Internal Medicine*, *169*(7), 467–473.

United Nations. (n.d.). *Net-zero coalition*. United Nations. Retrieved December 10, 2024, from https://www.un.org/en/climatechange/net-zero-coalition

Vandyck, T., Keramidas, K., Kitous, A., Spadaro, J. V., Van Dingenen, R., Holland, M., & Saveyn, B. (2018). Air quality co-benefits for human health and agriculture counterbalance costs to meet Paris Agreement pledges. *Nature Communications*, *9*(1), 4939.

Verma, A., Harsha, V., & Subramanian, G. H. (2021). Evolution of urban transportation policies in India: A review and analysis. *Transportation in Developing Economies*, *7*(2), 25.

Vohra, K., Vodonos, A., Schwartz, J., Marais, E. A., Sulprizio, M. P., & Mickley, L. J. (2021). Global mortality from outdoor fine particle pollution generated by fossil fuel combustion: Results from GEOS-Chem. *Environmental Research*, *195*, 110754.

Whitmee, S., Green, R., Belesova, K., Hassan, S., Cuevas, S., Murage, P., … & Haines, A. (2024). Pathways to a healthy net-zero future: report of the Lancet Pathfinder Commission. *The Lancet*, *403*(10421), 67-110.

Wilkinson, P., Smith, K. R., Davies, M., Adair, H., Armstrong, B. G., Barrett, M., … & Chalabi, Z. (2009). Public health benefits of strategies to reduce greenhouse-gas emissions: household energy. *The Lancet*, *374*(9705), 1917-1929.

Woodcock, J., Edwards, P., Tonne, C., Armstrong, B. G., Ashiru, O., Banister, D., ... & Roberts, I. (2009). Public health benefits of strategies to reduce greenhouse-gas emissions: urban land transport. *The Lancet*, *374*(9705), 1930-1943.

Yamamoto, S. S., Phalkey, R., & Malik, A. A. (2014). A systematic review of air pollution as a risk factor for cardiovascular disease in South Asia: Limited evidence from India and Pakistan. *International Journal of Hygiene and Environmental Health*, *217*(2), 133–144.

7. Appendix

Table A1: Description of the most commonly used models in the corpus

MODEL	FOCUS	DESCRIPTION
TM5-FASST	Atmospheric Chemistry, Emissions to Concentrations, Human Health Impacts	The TM5 Fast-Atmospheric Chemistry and Transport is a global model that calculates pollutant concentrations present in the air based on emissions. It further evaluates the impact of these pollutants on human health, crop production, and climate. The model used annual emission data, which is typically grouped by country or region, as its input.
GAINS	Emissions, Human Health Impacts	The Greenhouse Gas and Air Pollution Interactions and Synergies model tool is a tool that helps in finding smart and affordable ways to reduce emissions arising from various sources like factories, cars, agriculture etc. while addressing both air pollution and climate change. GAINS helps to design policies that clean the air and fight climate change at the same time. It works in three main ways: simulation, cost effectiveness analysis and cost benefit assessments.
GEMM	Human Health Impacts	The Global Exposure Mortality Model was developed to estimate the non-accidental mortality burden associated with exposure to

		air pollution, particularly fine particulate matter (PM2.5) using data from 41 cohorts from 16 countries. The model focuses on key disease endpoints from the GBD Studies including ischemic heart disease (IHD), stroke, chronic obstructive pulmonary disease (COPD), lung cancer, and lower respiratory infections (LRIs).
GCAM	Emissions	The Global Change Analysis Model is an integrated human-earth system model developed by the Joint Global Change Research Institute (JGCRI) that represents the interconnections of energy, land-use, economy, water and climate systems.
GEOS-Chem	Atmospheric Chemistry, Air Quality, Emissions	GEOS-Chem is a tool used for studying air quality and atmospheric composition on local to global scales. The off-line mode uses NASA’s weather data to stimulate atmospheric changes from 1979 to the present. These simulations can be done globally or for a specific region. The online mode works with weather or climate models to include detailed chemical reactions, aerosols, emissions, and pollution movement during simulations. GEOS- Chem model is also used for inverse modeling and data analysis.

POLES	Emissions	The Prospective Outlook on Long-term Energy Systems is a global energy model for the development of energy and greenhouse gas (GHG) emissions scenarios. It enables the assessment of the contribution of various energy types (fossil fuels, nuclear, renewables) and energy vectors to future energy needs. It also calculates changes in GHG emissions endogenously for the energy-industry sectors and through linkage with specialist models for GHG emissions from agriculture and land-use, and air pollution.
Global InMAP	Emissions to Concentrations, Human Health Impacts	InMAP is a recently developed model that estimates human health impact caused by air pollutant emissions and how these impacts are distributed among different groups of people. The InMAP model works by taking annual emissions data from a map and dividing it across a grid. It calculates how these emissions change PM2.5 pollution levels and estimates how this affects people's exposure using population data. The model also looks at how different groups of people are impacted by PM2.5, even if they live close to each other. It then uses health studies to estimate the health effects of the pollution and can optionally convert these impacts into economic costs using a standard value for human life. This gives a full picture of the effects of emissions.