Review

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Exposure to air pollution from coal-fired power plants and impacts on human health: a scoping review

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Abstract: Communities living in proximity to coal-fired power plants (CFPPs) may be at greater risk of negative health impacts from exposure to air pollution than communities living further away. The aim of this scoping review was to provide an update on the evidence of the health risks of air pollution exposure associated with living in proximity to CFPPs and to evaluate the relationship between residential proximity and the extent of the health burden. We followed the PRISMA-ScR guidelines and searched Google Scholar, PubMed, ScienceDirect, Scopus and Web of Science for relevant studies from inception up to 31 January 2024. Fifty-six studies were included with most articles published from 2016 to 2023 (n=33, 59 %) and 35 were in high income countries (63 %). Living close to CFPPs was frequently associated with increased odds or likelihood of respiratory disorders, adverse birth outcomes and child developmental issues. Interventions such as emission control systems or total shutdown of CFPPs led to improved health among communities living near CFPPs. The review highlights the health impacts from air pollution associated with living in proximity to CFPPs and the need for policy measures to reduce air pollution by installing emission control technologies or transitioning to cleaner energy sources.

Keywords: air pollution; coal; environmental health; health impact; particulates; power plant

Introduction

Coal is a cheap and large fuel source for power generation worldwide, accounting for 35 % of the global electricity mix in 2023 Energy Institute [1]. Over the years, the use of coal has negatively impacted the environment and human health. Coal-fired power plants (CFPPs) burn coal to produce electricity and are significant sources of air pollution. Coal combustion releases air pollutants: carbon dioxide (CO_2), sulphur dioxide (SO_2), nitrogen oxides (NO_x), particulate matter (PM), potentially toxic elements (arsenic [As], mercury [Hg], and lead [Pb]), organic hydrocarbons polycyclic aromatic hydrocarbons (PAHs), volatile organic compounds and fly ash as a residue into the atmosphere [2].

According to the International Energy Agency (IEA), China, United State of America (USA) and India are among the countries with the highest coal consumption in 2023 [3]. On the other hand, countries with the highest percentage of electricity produced from coal include Botswana, Kosovo, Mongolia and South Africa have (96 , 88, 84 and 84 %, respectively) [1]. Reports show that there has been an increase in operating coal capacity (45.5 GW in 2022 and 48.6 GW in 2023) with new coal plants coming online in 2023 [4, 5]. Additionally, the number of coal-fired units that are scheduled to retire has lowered in 2023 compared to 2022.

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Both long-term and short-term exposure to air pollution affects lung and heart functioning. Several studies link exposure to particulate matter with a diameter of 2.5 μm or less ($PM_{2.5}$) and respiratory diseases [6–9]. Exposure to $PM_{2.5}$, particularly in children, has been associated with increases in the risks of poor lung, neurological and brain development [10, 11]. Studies have also shown that pregnant women who live in areas with high levels of air pollution are at greater risk of adverse birth outcomes compared to those living in areas with low levels [12–15]. Air pollution can trigger asthma attacks, cause shortness of breath, coughing, suffocation and headaches in individuals living in areas near CFPPs. Increases in $PM_{2.5}$ concentrations have been associated with increases in lung cancer mortality rates [16]. Air pollution from CFPPs has been linked to nearly 500,000 premature deaths of individuals 65 years and older in the USA [17].

In addition to air pollution that emanates from CFPPs, coal ash also poses a major health risk. Coal ash is often disposed of in storage ponds or landfills near CFPPs. Also known as coal combustion residuals, coal ash is the byproduct of burning coal to generate electricity. Many coal ash landfills are neither capped nor lined, which allows fugitive dust to be blown into the air and leachate to contaminate surface, and groundwater. Even after a CFPP is closed, the coal ash landfills may remain for a long time, posing a persistent environmental and health risk to nearby communities as emphasized recently by Zhang and Zierold [18].

Communities that live near pollution sources are at higher risk of exposure to air pollution leading to adverse health effects compared to communities living far from pollution sources. Communities far from pollution sources can also be vulnerable to air pollution as it can travel to neighbouring states or provinces located downwind [19]. Prevailing wind patterns contribute to the long-range transportation of air pollutants. Considering this, several modelling studies have projected health and cost benefits of reducing emissions associated with CFPPs [20, 21]. As per the Paris Agreement, all regions should have phased out coal which includes electricity production by between 2030 and 2040 [22]. Few studies investigated the extent of health impacts of exposure to air pollution in individuals living near CFPPs. Only Amster [23] has evaluated literature on the impacts of emissions from CFPPs on mortality and morbidity. Therefore, this review aims to provide an update of the evidence of the health impacts associated with air pollution exposure among communities living in proximity to CFPPs. We also evaluated the relationship between the distance from the CFPPs and the risk of negative health outcomes. We did not isolate emissions from CFPPs' stacks vs. coal ash hence our review considers all air pollution around a CFPP.

Methods and materials

This scoping review followed the guidelines by the Joanna Briggs Institute [24]. The reporting of the scoping review was guided by the Preferred Reporting Items for Systematic Reviews and Meta-Analyses Extension for Scoping Reviews (PRISMA-ScR) guidelines and the PRISMA-ScR checklist (Table S1) [25]. We developed and registered the review protocol with the Open Science Framework [26]. More details are presented in the published review protocol [27].

Information sources

In summary, we searched five databases, i.e., Google Scholar, PubMed, ScienceDirect, Scopus and Web of Science, for relevant studies. We also searched grey literature for reports from federal agencies, commercial and non-profit organizations. The search was conducted on 5 March 2024. Additional records were identified by screening the reference lists of included articles.

Search strategy

The medical subject headings (MeSH) were used to develop the search strategy. The search terms used were ("air pollutants" OR "air pollution") AND ("coal-fired power plant*" OR "coal-fired power station*") AND health. The search was restricted to English language published up to and including 31 January 2024. The full search strategy is shown in the supplementary material (Table S2).

Eligibility criteria

The Population, Exposure, Context, Outcome and Study design (PECOS) framework was followed to identify relevant articles. The inclusion criteria consisted of articles that focused on humans of all ages, gender and geographical regions including infants and pregnant women exposed to air pollution from CFPPs. The proximity of the population to CFPPs was considered. Articles that measured at least one health outcome were included. Studies focussing on health risk assessment, exposure risk assessment, health impact assessment and health modelling only were excluded. Studies focussing on *in vivo*, animal, and environmental samples only were excluded. Occupational exposure was not considered. Reviews, conference abstracts, editorials, and dissertations were excluded.

Screening

The retrieved articles were uploaded on Endnote reference management software and duplicates were removed. The articles were then exported to Rayyan online tool for the screening process [28]. The remaining duplicates were removed. Four reviewers (CW, CYW, NM and TK) independently screened the title and abstracts of articles according to the inclusion and exclusion criteria. This was followed by the full-text screening of the relevant articles. Discrepancies were resolved through discussion until consensus was reached.

Data extraction

A data extraction tool was developed and piloted against 10 studies. Data was independently extracted from eligible studies by five reviewers (CH-D, CW, CYW, NM and TK). The data extracted from the studies included the following: author(s), year of publication, study design, distance from CFPP, type of pollutant, health outcomes, and key findings.

Quality assessment

The methodological quality of the included studies was assessed by one reviewer using the Critical Appraisal Skills Programme (CASP) checklists for cohort, case control and qualitative studies (Table S3A and S3B) [29, 30]. We used the National Heart, Lung and Blood Institute (NHLBI) Quality Assessment Tool for Observational Cohort and Cross-sectional studies checklist for the cross-sectional studies and Before-After (Pre-Post) studies checklist for controlled intervention studies (Table S3B and S3C) [31]. We used the Authority, Accuracy, Coverage, Objectivity, Date, Significance (AACODS) checklist for grey literature (Table S3D) [32]. The CASP tool consists of questions that examine the study validity, results, and relevance. There were three options to each question: yes, no, cannot tell. For the NHLBI tool, the options were yes, no, cannot determine or not applicable (NA). We calculated the percentage of "yes" for each article. Questions that were answered with "can't tell" or "cannot determine" or "NA" were excluded from the calculation. No studies were excluded based on the CASP, NHLBI and AACODS results.

Impact of CFPPs closure

While we focused on finding studies that presented data on the health impacts associated with living near CFPPs (i.e., our search terms did not include the impact of CFPPs closures on health) we also noted that some of these studies included mention of CFPPs closure, hence we note those findings here too.

Data synthesis and analysis

Descriptive tables were created to summarize the characteristics of the studies and synthesized the studies by the main themes from extracted data. The tables consisted of (a) sample characteristics, (b) distance from the CFPP, (c) pollutant studied, (d) health outcomes and (e) key findings.

Results

Descriptive findings

The initial literature search identified 3 449 records from the five databases, and 30 records from the grey literature with 10 additional records found through the reference lists (Figure 1). For the database search, duplicates were removed, and 2,435 records were screened by title and abstract, and 90 studies were selected for a full-text review. For the grey literature search, 40 records (30 reports and 10 additional studies) were retrieved and assessed for eligibility. After the full-text assessment of the 90 studies and 40 records, 56 studies (including two reports) met the inclusion criteria and were included in the review. Multiple studies (presented in more than one study) of the same cohort were only considered if the results of the health outcomes were different. The same cohorts of pupils [33, 34], non-smoking mothers and newborns [35–42], and 6–14-year-old children [43–45] with different health outcomes were included.

The four countries with the highest number of studies were USA (n=21), China (n=10), Israel (n=6) and India (n=5) (Figure 2). There were no studies observed for Africa and South America. Table 1 shows the descriptive characteristics of the included studies. A detailed description of the

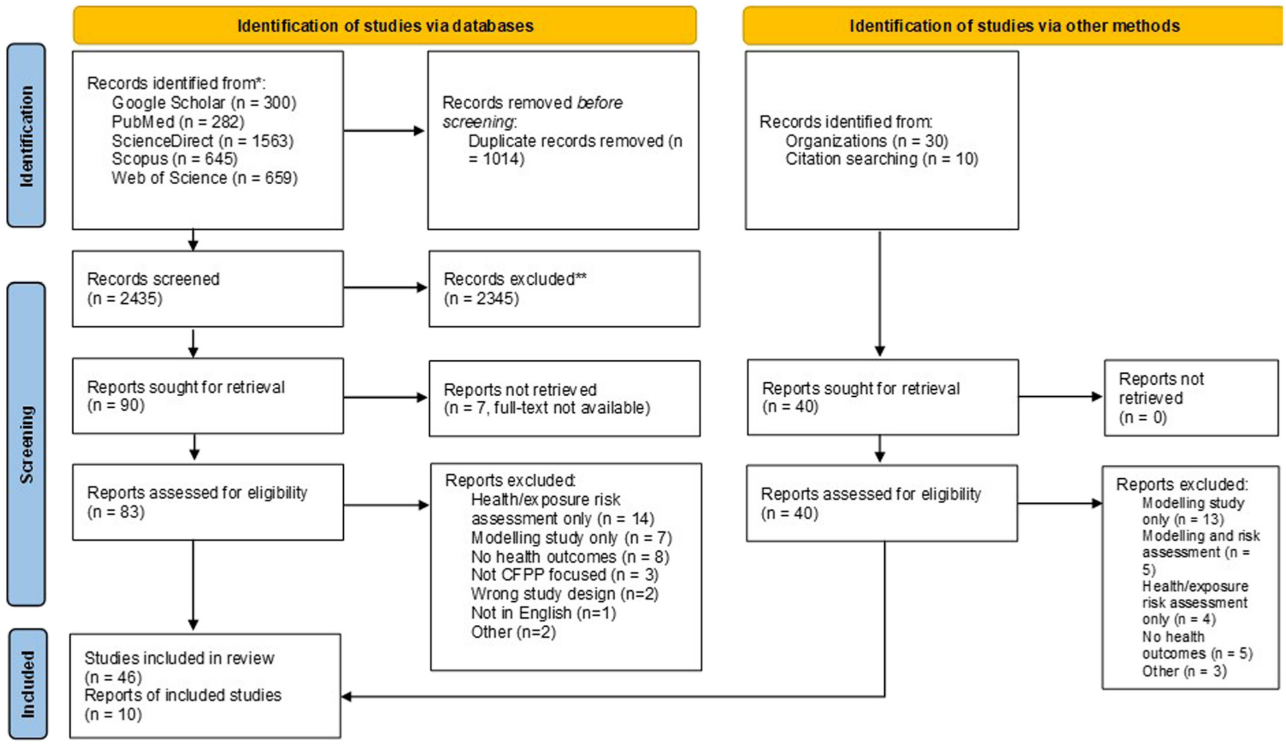

Figure 1: PRISMA flow diagram of the study selection.

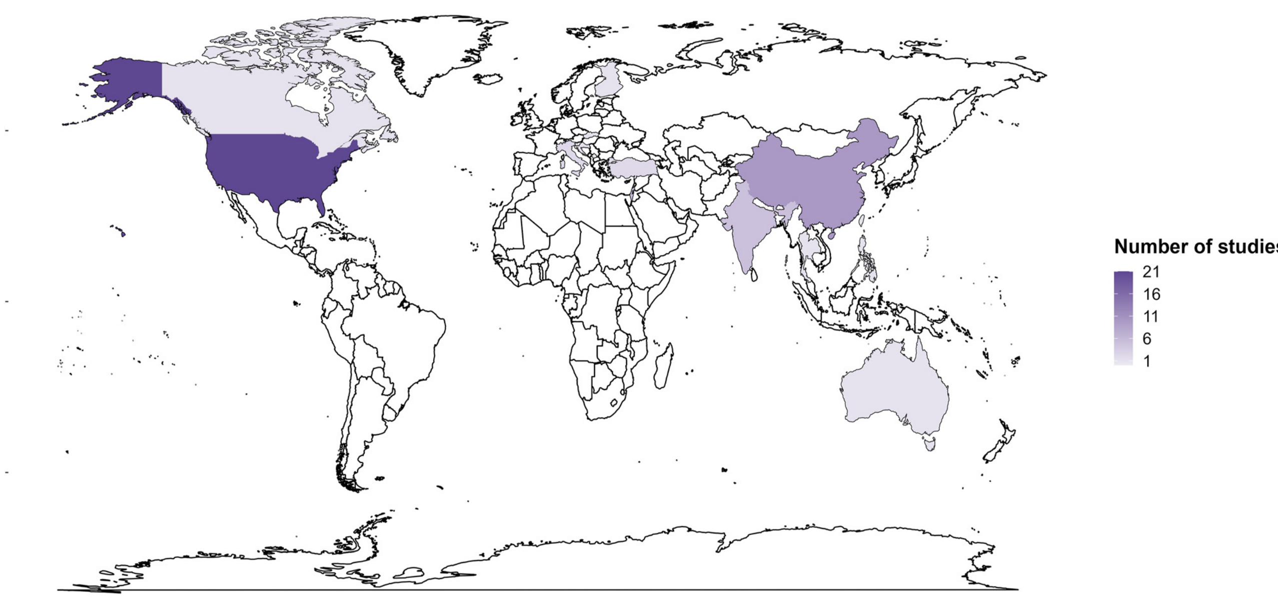

Figure 2: Map showing the distribution of included studies.

characteristics of the included studies is shown in Table 2. About 59 % of the studies were published between 2016 and 2023. Cross-sectional (55 %) and cohort (33 %) were the most common study designs followed by intervention (4 %) and qualitative studies (4 %). Commonly investigated air pollutants included SO_2, $PM_{2.5}$, PAHs and NO_x. Six studies compared the health outcomes in exposed and control groups [51, 65, 67, 70, 75, 86]. Twenty-three studies included children (3–14 years) [33, 34, 43–46, 51–53, 55, 58, 59, 61, 67, 71–73, 77–79, 81, 84, 85], nine studies included mothers and infants or neonates [35–42, 60] and four studies considered births as the study population [50, 64, 82, 83].

Table 1: Descriptive characteristics of included articles (n=56).

Items	Number of studies n, %
Income group/level	
High income	35 (63)
Upper middle income	14 (25)
Lower middle income	6 (11)
Other (multi-country)	1 (1)
Publication year	
≤2000	6 (11)
2001–2005	3 (5)
2006–2010	5 (9)
2011–2015	9 (16)
2016–2020	18 (32)
2021–2023	15 (27)
Study design	
Cross-sectional	31 (55)
Cohort	19 (33)
Intervention	2 (4)
Qualitative	2 (4)
Other	2 (4)
Pollutant(s) *(some articles included more than one pollutant)*	
$PM_{2.5}$	13
SO_2	22
PAHs	9
NO_x	8
Hg	6
PM_{10}	6
NO_2	4
O_3	3
Pb	3
As	2
CO	2
Fly ash	2
$SO_2/PM_{2.5}$	2
PM_1	1
Other	4
NR	7
Health outcomes *(some studies included more than one pollutant)*	
Respiratory disorders	31
Adverse birth outcomes	11
Neurodevelopment disorders	9
Cause-specific and all-cause mortality	8
Foetal and child development	4
Heart conditions	4
Cancer	3
Internalizing disorders	2
Other	7

Studies that measured emissions from CFPPs' stacks

Four studies reported on the air pollution data near CFPPs [40, 41, 46, 49]. A study by Aekplakorn et al. [46] used daily outdoor air pollution data from air monitoring stations around the CFPP in Thailand. The study found low levels of SO_2 and PM_{10}, below Thai daily 24-h mean SO_2 and PM_{10} standards (300 μg/m^3 SO_2 and 120 μg/m^3 PM_{10}). This was attributed to the recent installation of scrubbers in the CFPP and use of low-sulphur coal. Lower pulmonary function in asthmatic children in the study villages were associated with increases in daily PM_{10} concentrations. Barik et al. [49] carried out real-time air quality monitoring to determine the levels of air pollutants in seven locations in the study area around two CFPPs in central India. The findings show that the PM concentrations were higher in areas near the two CFPPs. PM (PM_{10}, $PM_{2.5}$ and PM_1) concentrations were measured in the morning, afternoon and evenings. Most locations had PM concentrations exceeding regulatory limits set by National Ambient Air Quality Standards (NAAQS) and WHO. The highest concentrations of PM_{10}, $PM_{2.5}$ and PM_1 were reported in two locations that are separated by a distance of 4 km.

Tang et al. [40] and Tang et al. [41] reported on a previous study that measured $PM_{2.5}$ and PAH concentrations in the same study area in Tongliang, China, near the CFPP. The air quality monitoring was done before the shutdown of the CFPP. The higher PAH concentrations and seasonal variations in air pollution in the area were largely attributed to the CFPP emissions. PAHs and $PM_{2.5}$ concentrations were reported to be higher in winter and low in summer. PAHs of higher molecular weight were 1.5–3.5 times higher during the CFPP operational period. The air monitoring data showed that the CFPP was a major contributor to PAHs in the air.

Association between distance between community and CFPP and health/risks impacts

Ten studies found a significant association between distance from CFPPs and the risk of negative health outcomes [41, 64, 68, 70, 75, 76, 78, 83, 85, 86]. Individuals of age ≥35 living in villages around the Seyitömer CFPP in Turkey had statistically significant more frequent complaint of chest tightness and repeated coughs for more than a year than individuals of age ≥35 in control villages (chest tightness: Fisher's exact chi-square $p=0.0006$ and chi-square=14.774, $p=0.0001$; coughs: chi-square=5.08, $p=0.024$) [70]. A significant increased prevalence rate of throat clearing was reported for individuals living near CFPP in Finland compared to its reference area (further away from CFPP) ($p<0.001$) [76]. Using negative binomial multivariable models Rodriguez-Villamizar et al. [78] found a significant

Table 2: Detailed characteristics of the included studies.

Study ID	Country	Income level	Study design	Sample characteristics	Distance from CFPP	Pollutant(s) studied	Health outcomes	Key findings
Aekplakorn et al. [46]	Thailand	UMI	Cross-sectional	n=175 children (6–14 years) (n=83 asthmatic, n=92 non-asthmatics)	7–8 km	SO_2 & PM_{10}	Pulmonary function	A weak association was observed between reduced pulmonary function and changes in the ambient concentration of SO_2. An association was observed between increased daily PM_{10} levels and lower pulmonary function in asthmatic children.
Amster et al. [47]	Israel	HI	Cross-sectional	n=2,244 adults (18–75 years)	20–30 km	NO_x & SO_2	Respiratory symptoms	Data did not support an association between CFPPs emissions and prevalence of chronic obstructive pulmonary disease or asthma. Nearly all the respiratory symptoms studied were however associated with NO_x power plant emissions.
Barbhaya et al. [48]	India	LMI	Cross-sectional	n=NR, individuals in 597 districts (15–69 years)	NR	$PM_{2.5}$	All-cause mortality	47,000 premature adult deaths in India were attributable to CFPPs in 2014 and were concentrated in the 10 % of Indian districts that housed these CFPPs.
Barik et al. [49]	India	LMI	Cross-sectional	NR	≤20 km	PM_1, $PM_{2.5}$, PM_{10}	URTI	Increased average annual prevalence of URTI was observed in the central Indian population residing near coal-fired TPPs.
Barrows et al. [50]	India	LMI	Cross-sectional	n=NR, live births and infant deaths	0–50 km	$PM_{2.5}$, NO_2, SO_2	Infant mortality	1 GW increase in coal-fired capacity increased infant mortality rates by roughly 15 % relative to other districts in the same state. Impact of infant mortality rate was reported to be larger for older plants, located in districts with higher baseline pollution levels and burning domestic rather than imported coal. Urban areas within districts were more exposed to coal-powered capacity than rural areas as CFPPs were located in urban areas
Bencko et al. [51]	Slovakia	HI	Cross-sectional	n=107 children (9.5–11 years) (n=56 exposed, n=51 control)	NR	As	Hearing loss	Higher rate of enlarged and large tonsils and adenoids and concomitant phlegm-pus flow in the posterior nasopharynx was found in the exposed group compared to the control group. Higher incidence of repeated rhinitis was observed in the exposed group.

Table 2: (continued)

Study ID	Country	Income level	Study design	Sample characteristics	Distance from CFPP	Pollutant(s) studied	Health outcomes	Key findings
Blanchard et al. [52]	USA	HI	Cross-sectional	n=NR, children (3–5 years)	NR	Hg	Autism	Higher levels of ambient mercury were geographically associated with point sources of mercury emission, such as CFPPs and cement plants with coal-fired kilns. School districts in closest proximity to these areas had the highest autism rates in the county.
Casey et al. [53]	USA	HI	Cohort	n=57,005 births	≤20 km	$PM_{2.5}$	Preterm birth	The prevalence of preterm birth decreased near CFPPs after retirement, with larger reductions closer to CFPPs.
Casey et al. [54]	USA	HI	Intervention	n=207 asthmatic individuals (average age=45 years)	NR	SO_2	ER asthma visits and hospitalization	The reductions in CFPP air pollution exposure after retirements and SO_2 control installations translated to fewer asthma-related ERVs and hospitalizations, as well as fewer average daily short-acting beta-agonists (SABA) uses.
Chen et al. [55]	Taiwan	HI	Cross-sectional	n=252 participants (children, 9–15 years; elderly, >55 years) (n=111 high exposure group, n=141 low exposure group)	7–13 km (high exposure), 16–27 km (low exposure)	PAHs & heavy metals	Urinary metabolomic biomarkers linked to oxidative stress	Ambient concentration of vanadium and PAHs were significantly higher in high exposure groups that lived closer to the CFPP when compared to the low exposure group, for both children and elderly participants.
Chen et al. [56]	China	UMI	Cross-sectional	n=NR, individuals in 161 counties	≤50 km	SO_2	Respiratory and cardiovascular diseases mortality	The results reveal that air pollution from neighbouring power plants has significant negative effects on local public health, and the resulting treatment costs are enormous.
Chen et al. [57]	China	UMI	Time-series	n=NR	NR	SO_2	Respiratory disease and lung cancer mortality	SO_2 emissions have significantly negative effects on public health. SO_2 emissions resulted in 230,000 extra deaths every year and the related economic costs over the study period amount to RMB 8.179 billion
Collarile et al. [58]	Italy	HI	Descriptive cross-sectional	n=1,726 lung and bladder cancer cases (all ages)	NR	PM_{10}, C_6H_6, NO_2, SO_2	Lung and bladder cancer	An excess risk of lung and bladder cancer was associated with high residential exposure to benzene and NO_2 in women aged ≥75 years old.
Daouda et al. [59]	USA	HI	Cross-sectional	n=NR, neonates born to non-Hispanic Black and non-Hispanic White in 289 counties	NR	SO_2 converted to $PM_{2.5}$	Preterm birth	A positive non-linear relationship between coal $PM_{2.5}$ and PTB rate was observed and plateaued at higher levels of pollution. Differential associations by maternal race were observed; the association was stronger for White women, especially at higher levels of coal $PM_{2.5}$ (>2.0 μg m^{-3}).

Table 2: (continued)

Study ID	Country	Income level	Study design	Sample characteristics	Distance from CFPP	Pollutant(s) studied	Health outcomes	Key findings
Datt et al. [60]	India	LMI	Cross-sectional	n=176,583 women (18–49 years) and children (6–60 months) (n=39,356 children, n=137,227 women)	NR	$PM_{2.5}$	Anaemia	The increase of coal units closer to residential areas had a stronger effect on the likelihood that the child was anaemic. A negative correlation was observed between distance from the coal primary sampling unit and the magnitude of the harmful impact of coal on women's health.
Dubnov et al. [61]	Israel	HI	Cohort	n=1,492 children (7–14 years)	≤10 km	NO_x & SO_2	Pulmonary function	A negative association was found between changes in the pulmonary function results and the estimated individual levels of air pollution. The estimated adverse effect of NO_x & SO_2 on children's pulmonary function growth was found to range from 4 % for the mean level of air pollution to 10 % for the maximum concentration of these pollutants.
Fan and Wang [62]	USA	HI	Cross-sectional	n=NR, U.S residents (≥65 years)	≤50 km	$PM_{2.5}$	Mortality	Instrumental variable and difference-in-differences approaches found that power plant retirements lead to reductions in $PM_{2.5}$ levels and consequently decreased monthly mortality among older adults. The mortality effects were higher among males than females and its impact was the greatest among people >75 years.
Goren and Hellmann [33]	Israel	HI	Cohort	n=NR, 2nd, 5th and 8th grade pupils (8, 11 and 14 years) (1980: n=737 pupils, 1983: n=698 pupils, 1986: n=993 pupils, 1989: n=963 pupils)	≤19 km	SO_2, NO_x, O_3, CO, total hydrocarbons	Asthma and related respiratory conditions	The rise in prevalence of asthma was not related to any residential area. Air pollution levels were very low and previous health studies in the area around the CFPP did not find any negative health effects.
Goren et al. [63]	Israel	HI	Cohort	n=30,000 patients	≤10 km	SO_2, NO_x, O_3, CO, total hydrocarbons	Respiratory diseases	The air pollution levels in both 1980 (before CFPP operation) and 1983 (when CFPP was in operation) were highest in the community located in the city (closer to CFPP). Air pollution levels measured around the CFPP were low and did not seem to cause adverse health effects.
Goren et al. [34]	Israel	HI	Cohort	n=NR, 2nd and 5th grade pupils (1980: 2nd graders n=991 and 5th graders n=999, 1983: 2nd	≤19 km	NR	Pulmonary function	No negative health effects among children residing in areas expected to be affected by the operation of CFPP as compared to the

Table 2: (continued)

Study ID	Country	Income level	Study design	Sample characteristics	Distance from CFPP	Pollutant(s) studied	Health outcomes	Key findings
				graders n=785 and 5th graders n=693)				expected low-pollution areas. The respiratory symptoms among children were linked to age, epidemics and background variables rather than air pollution levels.
Ha et al. [64]	USA	HI	Cohort	n=423,719 births	<5 to ≥20 km	$PM_{2.5}$	Preterm delivery, very preterm delivery, and low birth weight	Women who lived closer to coal and solid waste power plants were exposed to higher levels of $PM_{2.5}$. When exposure was changed to the number of plants within 20 km, CFPPs had the highest association with all adverse birth outcomes. About 1.8 % increased odds for PTD, 2.2 % for VPTD, and 1.1 % for term LBW was observed for each 5 km closer to any power plant.
Hagemeyer et al. [65]	USA	HI	Qualitative	n=401 adults (≥18 years) (n=231 exposed population, n=170 non-exposed population)	<1 km (exposed), ~97 km (non-exposed)	NR	Respiratory symptoms	Adults residing near a CFPP with a coal ash facility (exposed) were more likely to report respiratory symptoms than the non-exposed population. Participants living near coal ash storage who spent more time outside were more likely to report having a respiratory infection.
Henneman et al. [66]	USA	HI	Cross-sectional	n=NR	NR	SO_2 converted to $PM_{2.5}$	Cardiac, respiratory health and all-cause mortality	Rates reductions in six cardiac and respiratory health outcomes decreased with decreases in $PM_{2.5}$ and coal exposure. A secondary analysis found that nonlinearities in relationships between changing health outcome rates and coal exposure may explain differences in their associations.
Henry et al. [67]	Australia	HI	Cohort	n=99 primary schoolchildren with history of wheezing (n=49 in exposed area Lake Munmorah (LM), n=50 in control area Nelson Bay (NB))	≤5 km (exposed area), ~80 km (control area)	NO_x & SO_2	Asthma	The asthma symptoms were similar in exposed and control areas and the frequency of asthma was low on both areas. SO_2 and NO_x concentrations were within recommended guidelines, air quality had no effect on asthmatic symptoms
Hii et al. [68]	USA	HI	Cross-sectional	n=2,327 adults (21–74 years old)	≤35 km (within), >35 km (away)	NR	Pulmonary function	Adults living near 1 of 11 CFPPs may have worse pulmonary function. The odds ratio of FEV1/FVC values below 80 % for those living within 35 km of a CFPP was 1.24 (95 % CI, 0.90–1.70) when compared to those living greater than 35 km from a plant. There was

Table 2: (continued)

Study ID	Country	Income level	Study design	Sample characteristics	Distance from CFPP	Pollutant(s) studied	Health outcomes	Key findings
								a statistically significant higher percentages of Black and Hispanic survey respondents living near CFPPs.
Kamath et al. [69]	India	LMI	Cross-sectional	n=3,533 participants from 5 villages	>5 km to<10 km	$PM_{2.5}$, Hg, Pb, other heavy metals	Respiratory function	There was significant association between abnormalities in pulmonary function tests and those living in the vicinity of the CFPP (p<0.05). Those living near the CFPP had higher abnormal lung function test compared to those residing far.
Karavuş et al. [70]	Turkey	UMI	Cross-sectional	n=502 individuals (≥15 years) (n=277 people in exposed villages, n=225 people in control villages)	≤5 km (exposed villages), >30 km (control villages)	NR	Respiratory complaints and function	Individuals over 35 years in villages around CFPP had more frequent complaints of chest tightness than those in control villages (p=0.0001). The FEV1, FVC, and FEF25–75 % of the nonsmokers living in the villages around power plant were statistically significantly reduced compared to non-smokers living in the control villages.
Komisarow and Pakhtigian [71]	USA	HI	Cross-sectional	n=NR, children (0–4 years)	≤10 km	$PM_{2.5}$	Asthma-related conditions	After closure of CFPPs in 2012, ZIP codes in close proximity to the three CFPPs experienced reductions in emergency department visits for asthma-related conditions among children. An increasingly negative pattern of estimated effects for the years 2012 and later was observed, which suggests that the effects of CFPP closures increase over time.
Komisarow and Pakhtigian [72]	USA	HI	Cross-sectional	n=NR, students in public elementary schools	≤10 km (treatment group), >10 km (control group)	NO_2, SO_2, $PM_{2.5}$	Asthma-related conditions	After closure of CFPPs, school-level absence rates decreased by around 6 % in schools located near the CFPPs. School absence reductions were larger for boys than for girls. Evidence suggests that children's respiratory health improved following the closure of the 3 CFPPs. A decline in rates of emergency department visits for asthma-related conditions was observed among school-age children in ZIP codes near the CFPPs compared to ZIP codes farther away.
Lee et al. [35]	China	UMI	Cohort	N=NR, mothers (≥20 years) and newborns (2002 cohort: n=110 women and newborns, 2005	≤2.5 km	Hg, Pb, PAHs	Neurodevelopment outcomes	An inverse association between prenatal exposure to PAH, measured by PAH-DNA adducts in cord blood, and LINE1

Table 2: (continued)

Study ID	Country	Income level	Study design	Sample characteristics	Distance from CFPP	Pollutant(s) studied	Health outcomes	Key findings
				cohort: n=107 women and newborns)				methylation status in both cohorts combined; and a direct correlation between LINE1 methylation status and child IQ scores at 5 years of age in the 2002 cohort was observed.
Minichilli et al. [73]	Italy	HI	Population-based cohort	n=144,019, all ages	NR	NO_x & SO_2	Natural and all-cause mortality	Exposure to SO_2 from CFPP and ISDI were significantly correlated ($p<0.001$). An association was also found in both males and females between increasing exposure to SO_2 and diseases of the nervous system, and sense organ circulatory and respiratory system. The hospitalization data supported the mortality results.
Mohorovic [74]	Croatia	HI	Cohort	n=704, pregnant women	3.5–12 km	SO_2	Preterm delivery and low birth weight	A greater and longer exposure to SO_2 emissions during the initial 2 months of pregnancy resulted in a significantly shorter gestation at the end of the 1st and 2nd month of pregnancy ($p=0.008$, $p=0.016$, respectively) and in lower birthweight of newborns ($p=0.016$, $p=0.026$, respectively).
Pala et al. [75]	Turkey	UMI	Cross-sectional	n=2,819 individuals (≥15 years) (n=2,350 study group, n=469 control group)	1.5–12 km (study group), ~22 km (control group)	NR	Respiratory function	FEV1 and FVC averages for the study group villages were significantly lower than those for the control group and residents directly wind of the power plant's smokestack showed greater impairment of respiratory functions compared with residents upwind
Perera et al. [36]	China	UMI	Cohort	n=100 nonsmoking women (≥20 years) and newborns	≤2.5 km	PAHs	Child IQ	CFPP was the major source of environmental PAHs. After adjusting for potential confounders, neither PAH-DNA adducts nor exposure to ETS had significant main effects on IQ.
Perera et al. [37]	China	UMI	Cohort	n=NR, nonsmoking women (≥20 years) and their newborns (2002 before CFPP shutdown: n=110, 2005 after CFPP shutdown: n=107)	≤2.0 km	PAHs	Child neurodevelopment	PAH–DNA adducts in cord blood were significantly associated with DQ decrements in the motor area and in the average DQ among children who were *in utero* during the operation of the CFPP (2002 cohort), however these significant associations were not seen among children who were *in utero* after the CFPP had been shut down (2005

Table 2: (continued)

Study ID	Country	Income level	Study design	Sample characteristics	Distance from CFPP	Pollutant(s) studied	Health outcomes	Key findings
								cohort). In the 2002 cohort, PHA-DNA adducts were associated with an ~2-fold increased odds of developmental delay in the motor area.
Perera et al. [38]	China	UMI	Cohort	n=255, nonsmoking women (≥20 years) and their newborns (2002 before CFPP shutdown: n=122, 2005 after CFPP shutdown: n=133)	≤2.5 km	PAHs	Neurodevelopment outcomes	Mean telomere length (TL) was significantly higher in the 2005 cohort compared to the 2002 cohort. PAH-DNA adducts were significantly and inversely correlated with TL (p=0.018). A significant association between adducts and TL after adjusting for key covariates and cord Hg was observed (p=0.001). Longer telomeres in the 2005 cohort and the observed association between increased TL and higher levels of BDNF indicated benefits for health and development of children due to CFPP closure.
Pershagen et al. [76]	Finland	HI	Cross-sectional	n=8,762 individuals (15–64 years)	NR	SO_2 & dust	Respiratory symptoms	Plant A had the largest dust emissions. In area A there was a greater proportion of respondents reporting annoyance due to soot, dust, or fly ash in the subareas less than 2 km from plant A than in the subareas further away. Respiratory symptoms and diseases were more prevalent in areas with CFPPs (with more industries and roads) than in the reference areas.
Quizon et al. [77]	Philippines	LMI	Cross-sectional	n=370 households with children (6–10 years)	NR	NO_2, SO_2, PM_{10}	Respiratory symptoms and pulmonary function	The SO_2 and NO_2 levels are below the ambient standards. No significant association on the 8-h average for PM_{10} between the 'near' barangays (near CFPPs) and the 'far' barangays (far from CFPPs). PM_{10} and cigarette smoking were significant risk factors for wheezing and the predicted FEV1, respectively, reflecting the environmental exposure of children inside homes.
Rodriguez-Villamizar et al. [78]	Canada	HI	Cross-sectional	n=10,421 ED visits of asthmatic children (2–14 years)	NR	NR	ED asthma visits	There was an inverse association of the distance to the power plant (coefficient=−0.01 per km) with asthma visits.

Table 2: (continued)

Study ID	Country	Income level	Study design	Sample characteristics	Distance from CFPP	Pollutant(s) studied	Health outcomes	Key findings
Sears et al. [79]	USA	HI	Cross-sectional	n=221 children (6–14 years)	≤16 km	PM_{10}	Cognitive control	Among females, higher PM_{10} concentration was associated with a higher risk of commission errors, but the association between PM_{10} concentration and CPT commission errors was attenuated among males.
Severnini [80]	USA	HI	Cross-sectional	n=56,000 observations	NR	SO_2	Low birth weight	The shutdown of the TVA nuclear power plants in 1985 induced increases in coal-fired power generation and air pollution. Average birth weight declined ~134 g, or 5.4 log points, after the nuclear shutdown
Shabani Isenaj et al. [81]	Kosovo	UMI	Cross-sectional	n=NR, children hospitalized for respiratory diseases (0–18 years) (n=1,838 hospital admissions records, n=7,372 ambulatory visits)	NR	$PM_{2.5}$	Respiratory diseases	An increase in $PM_{2.5}$ led to significant increases in ambulatory visits on the first and second day after the pollution episode. Stationary hospital admissions only increased on the day following the pollution episode
Tang et al. [39]	China	UMI	Cohort	n=NR, nonsmoking women (≥20 years) and their newborns (2002 before CFPP shutdown: n=110, 2005 after CFPP shutdown: n=107)	≤2.5 km	PAHs	Neurodevelopment outcomes	In the two cohorts combined, PAH-DNA adducts were inversely associated with mBDNF as well as scores for motor ($p=0.05$), adaptive ($p=0.022$), and average DQ ($p=0.014$). BDNF levels were positively associated with DQ scores. The findings indicate that the closure of a coal-burning plant resulted in the reduction of PAH-DNA adducts in newborns and increased mBDNF levels that in turn, were positively associated with neurocognitive development.
Tang et al. [40]	China	UMI	Cohort	n=NR, nonsmoking women (≥20 years) and their newborns (2002 before CFPP shutdown: n=150, 2005 after CFPP shutdown: n=158)	≤2.5 km	PAHs	Foetal and child development	A decrease in detectable PAH-DNA adducts in the umbilical cord was observed in the 2005 cohort compared to the 2002 cohort. The percentage of infants categorized as delayed for the motor area was significantly lower in 2005 than in 2002. Initial birth weight, height and head circumference for infants in the 2002 cohort were lower or reduced than for those in the 2005 cohort.
Tang et al. [41]	China	UMI	Cohort	n=150 nonsmoking women (≥20 years) and their newborns	≤2.5 km	PAHs	Foetal and child development	Among females, high cord blood adduct level was significantly associated with smaller birth head circumference, as well as

Table 2: (continued)

Study ID	Country	Income level	Study design	Sample characteristics	Distance from CFPP	Pollutant(s) studied	Health outcomes	Key findings
								lower weight and shorter length. There was a significant association between longer duration of exposure and shorter length at birth and height.
Tang et al. [42]	China	UMI	Cohort	n=110 nonsmoking women (≥20 years) and their newborns	≤2.5 km	PAHs, Pb, Hg	Child neurodevelopment	Increased adduct levels were associated with decreased motor area development quotients (DQ), language area DQ and average DQ. Decrements in one or more DQs were significantly associated with cord blood levels of PAH–DNA adducts and lead, but not mercury.
Wilkie et al. [82]	USA	HI	Intervention	n=42,231 singleton births (CFPP-scrubber: n=42,231, CFPP-retired: n=41,218)	≤24 km	SO_2	Preterm birth	SO_2 emission reduction interventions were associated with a decrease in preterm birth for gestational parents living within 4–<10 miles (6.4–<16 km) compared with 10–<15 miles (16–<24 km) away, especially among those living near CFPPs that installed scrubbers on coal electricity generating units.
Yang et al. [83]	USA	HI	Cohort	n=1,676,798 observations of singleton births	32–48 km	SO_2	Low birth weight and very low birth weight	Babies born to mothers who live as far as 20–30 miles (32–48 km) away downwind from the power plant during the final stage of pregnancy were at greater risks of low birth weight and very low birth weight. Also, an increase of 1,000 tons of SO_2 monthly emissions that come from upwind directions during the final stage of pregnancy could increase the likelihood of low birth weight.
Yogev-Baggio et al. [84]	Israel	HI	Cohort	n=1,181 school children (n=537 healthy subgroup, n=357 chest symptoms subgroup, n=287 pulmonary disease subgroup)	NR	NO_x & SO_2	Pulmonary function	There was substantial decrease in the number of heathy children in the cohort in the most air polluted areas. Analysis of variance also confirmed that the interaction between air pollution levels and the children's health status was associated significantly with the children's PFT change.
Zhang et al. [85]	USA	HI	Cross-sectional	n=235 participants (6–14 years)	≤16 km	PM_{10}	Neurobehavioral problems	Significant and inverse associations were observed between distance to the nearest power plant and the four CBCL diagnoses (i.e., affective problems, anxiety problems, ADHD, and social problems). Statistically

Table 2: (continued)

Study ID	Country	Income level	Study design	Sample characteristics	Distance from CFPP	Pollutant(s) studied	Health outcomes	Key findings
								significant hot spots of participants who had elevated levels of attention deficit hyperactivity disorder, anxiety, and social problems were observed in the vicinity of the two CFPPs.
Zierold et al. [86]	USA	HI	Qualitative	n=401 residents (37–65 years) (n=231 exposed group, n=170 non-exposed group)	97 km (non-exposed group)	NR	Health symptoms	Adults who lived near the CFPP were significantly more likely to suffer from respiratory, gingiva, and skin symptoms. Adults living near the CFPP were significantly more likely to report having lung symptoms.
Zierold et al. [43]	USA	HI	Cross-sectional	n=261 children (6–14 years)	≤16 km	Fly ash	School and social competency	Children with fly ash in their homes scored an average 2.63 points lower on school competency compared with children who did not have fly ash in their homes.
Zierold et al. [44]	USA	HI	Cross-sectional	n=260 children (6–14 years) (n=62 children with internalizing behaviour, n=198 children without internalizing behaviour)	≤16 km	As, other heavy metals	Internalizing behaviour disorders	Exposure to zinc and imputed zirconium were associated with internalizing behaviours in children.
Zierold et al. [45]	USA	HI	Cross-sectional	n=266 children (6–14 years)	≤16 km	Fly (coal) ash	Depression	Children with fly ash indoors had more depressive problems compared to non-exposed children.
American Lung Association [2]	USA	HI	Report	NR	NR	$PM_{2.5}$, Hg, SO_2	CVD, asthma and other lung diseases	The EPA proposed a new requirement that all coal and oil-fired power plants that produce 25 MW of power for sale will be required to install cleanup technology such as scrubbers, as required by the Clean Air Act. This was done to reduce harmful air pollutants that make breathing difficult and causes asthma attacks and increase the risk of emergency room or hospital visits.
Health and Environmental Alliance [87]	Multi-country	NA	Report	NR	NR	CO_2, NO_x, $PM_{2.5}$, Hg	CVDs, respiratory symptoms and diseases, heart disease, and cancer	Significant evidence exists on how long-term exposure to these air pollutants affects the lungs and the heart. Recent research suggests that air pollution may also result in low birth weight and pre-term delivery because of maternal exposure during pregnancy.

World Bank income group/level: HI, high income; LMI, lower middle income; UMI, upper middle income; BDNF, brain-derived neurotrophic factor; CVD, cardiovascular diseases; DQ, developmental quotient; EDV/ERV, emergency department visits/emergency room visits; ETS, environmental tobacco smoke; FVC, forced vital capacity; FEV1, forced expiratory volume at 1 s; ISDI, Individual socioeconomic deprivation index; NA, not applicable; NR, Not reported; PAH, polycyclic aromatic hydrocarbons; PFT, pulmonary function test; URTI, upper respiratory tract infection.

inverse association between distance from CFPP and direction of emergency department visits in Alberta, Canada (coefficient=−0.001, 95 % CI: −0.01, −0.01, p=0.000). A weaker negative coefficient was found for the latitude function (coefficient=−0.72, 95 % CI: −1.05, −0.39, p=0.000) and a strong positive coefficient for the longitude function (coefficient=0.93, 95 % CI: 0.37, 1.49, p=0.001) for directional effects indicating that children with acute asthma at the east and southeast of the CFPP were at high risk of emergency department visits. A significant difference between perception of health of exposed population (Kentucky, USA) to non-exposed comparison group (Indiana, USA) was observed (p<0.0001). Adults living near the CFPP were significantly more likely to report having lung symptoms (96 vs. 82 %, p<0.0001), muscular symptoms (94 vs. 85 %, p=0.004), gingiva symptoms (34 vs. 19 %, p=0.009) and skin symptoms (60 vs. 33 %, p<0.0001) compared to the non-exposed comparison group. Adults who lived near the CFPP were significantly more likely to suffer from respiratory symptoms (AOR=5.27, 95 % CI: 2.16, 12), gingiva symptoms (AOR=2.46, 95 % CI: 1.46, 4.15), and skin symptoms (AOR=3.37, 95 % CI: 2.09, 5.43) [86].

Karavuş et al. [70] observed that the mean FEV1 value and FEF25-75 % was significantly lower for individuals in villages around the Seyitömer CFPP in Turkey compared to individuals of the control villages (p=0.0001 and p=0.0001, respectively). Similarly, Hii et al. [68] found lower FEV1/FVC ratio for those living within 35 km from one of the 11 CFPPs (OR=1.24; 95 % CI: 0.90, 1.70) compared to those living farther than 35 km away from a CFPP. In a study to evaluate the respiratory function of residents around the Orhaneli CFPP in Turkey, the study (exposed) group was observed to have increased odds of lower FEV1 (OR=1.60, 95 % CI: 1.29, 1.99, p=0.000) and FVC (OR=2.69, 95 % CI: 2.14, 3.39, p=0.000) values compared to the control group [75].

A cohort study investigating the association between residential proximity to CFPPs and risk of adverse birth outcomes in Florida, USA, found that pregnant women living near two or more CFPPs within a 20 km radius had a 12 % increased odds of term low birth weight (OR=1.12, 95 % CI: 1.03, 1.22), 20 % increased odds of preterm delivery (OR=1.20, 95 % CI: 1.14, 1.25), and 23 % increased odds of very preterm delivery (OR=1.23, 95 % CI: 1.10, 1.36) [64]. Tang et al. [41] evaluated the relationship between prenatal PAH and foetal and child development in Tangliang, China. There was a significant positive association between longer distance from CFPP and birth length (p=0.03).

Yang et al. [83] evaluated estimated effects of living downwind from CFPP and low birth weight and very low birth weight. Among mothers living in the four counties in USA, downwind of the CFPP during the last month of pregnancy, the low-birth-weight likelihood significantly increases by about 6.5 % (p<0.01), and the very low birth weight likelihood significantly increases by about 17.1 % (p<0.01). The effect of being downwind of the CFPP on low birth weight was also evaluated. The results showed that male maternal exposure to CFPP emissions during the last month of pregnancy could significantly increase the likelihood of low birth weight by 0.59 percentage points (p<0.01) and for female maternal exposure the likelihood of low birth weight could significantly increase by 0.45 percentage points (p<0.10) two months prior to the birth month.

Zhang et al. [85] examined the relationship between neurobehavioral symptoms in children and proximity to CFPPs in Louisville, USA. The findings showed that the nearest distance to a CFPP had a significant and negative regression coefficient with four neurobehavioral symptoms: affective problems (−0.395, p<0.10), anxiety problems (−0.609, p<0.05), ADHD (−0.531, p<0.05), and social problems (−0.934, p<0.01). Clustering analyses spatial showed that nearly all the hot spots (28 out of 30) for social problems were found in near two CFPPs (Mill Creek CFPP and Cane Run CFPP, <2 miles). A total of 29 statistically significant hots spots at the 95 and 90 % confidence levels were observed for ADHD problems, and these were clustered around the two CFPPs. Most hot spots for anxiety were identified near the Mill Creek CFPP (significant at 95 % confidence level) and three hot spots (significant at 99 % confidence level) near the Cane Run CFPP.

Eleven studies reported on benefits of interventions such as CFPP retirement and installation of emission control technologies and subsequent health outcomes [35, 37–40, 53, 54, 62, 71, 72, 82]. Studies by Lee et al. [35], Perera et al. [37], Perera et al. [38], Tang et al. [39] and Tang et al. [40] investigated the health benefits of shutting down the Tongliang CFPP in China in May 2004. The mother and infant cohorts were recruited in 2002 (before CFPP shutdown) and 2005 (after CFPP shutdown). The authors observed that the mean birth head circumference of the 2005 infants was significantly greater than that of the 2002 cohort (p<0.05). The mean PAH-DNA cord adduct level were significantly higher in the 2002 cohort than the 2005 cohort (p<0.05). Casey et al. [53] observed a significant association between CFPP retirements and decreases in the proportion of moderate to late preterm birth at 0–5 km (β=−0.020, 95 % CI: −0.031, −0.009) and 5–10 km (β=−0.016, 95 % CI: −0.025, −0.008) of the CFPP in California, USA. Another study by Casey et al. [54] observed a large reduction in risk asthma-related hospitalization and emergency room visits after the second quarter of the 2015 power plant energy transitions (one natural gas and three installed SO_2 scrubbers) in Louisville, USA (rate ratio [RR]=0.81, 95 % CI:

0.70, 0.92). The installation of the SO_2 scrubber was associated with a 17 % reduction in monthly average daily short-acting beta-agonists (SABA) use (RR=0.83, 95 % CI: 0.69, 1.00) and a 2 % reduction (95 % CI: −5 %, 1 %) for each month thereafter. Fan and Wang [62] observed that CFPP retirement reduced mortality of U.S adults older than 65 years by 3.6 % in treated counties (within 50 km downwind of CFPPs) between 1999 and 2013 ($p<0.01$), where retirement occurred between 2011 and 2013.

Komisarow and Pakhtigian [71] estimated the effect of coal-fired power plant closures on emergency department visits for asthma-related conditions among 0- to 4-year-old children in Chicago, USA. Emergency department visits for asthma-related conditions among 0- to 4-year-old children decreased by 12.1 % (95 % CI=−0.24, −0.02) near the three CFPPs following their closures relative to rates in zip codes farther away. In another study, Komisarow and Pakhtigian [72] observed that school-level rates of absences decreased by 6.14 % in schools located near the CFPPs (within 10 km) relative to those farther away following the closures in Chicago, USA (difference=1.01, $p<0.01$). Emergency department visits for asthma-related conditions after the closure of three CFPPs decreased by around 9 % ($p<0.05$) in school-aged children in zip codes near CFPPs compared to zip codes farther way.

Wilkie et al. [82] investigated the relationship between SO_2 emission reduction strategies and preterm birth in North Carolina, USA. Among births within 4–<10 miles (~6–16 km) of CFPPs, the prevalence of preterm birth decreased from 9.9 to 8.5 % after SO_2 scrubbers were installed and from 9.0 to 7.6 % after CFPPs were retired. Using difference-in-difference approach; for gestational parents within 4–<10 miles from a CFPP, the absolute prevalence of preterm birth was estimated to decrease by −1.5 % (95 % CI: −2.6, −0.4) associated with the installation of scrubbers and decrease by −0.5 % (95 % CI: −1.6, 0.6) associated with CFPP retirements and decreased by −1.0 % (95 % CI: −1.8, −0.2) with both SO_2 reduction intervention strategies.

Quality assessment in included studies

About 96.4 % (n=54) of the studies were classified as moderate to high quality and 3.6 % (n=2) were of low quality (supplementary material, Table S3A–D). Of the two studies with the lowest quality, one study did not clearly define the study population and inclusion criteria, and the other study did not clearly define the exposure measure and did not account for confounding factors [50, 51]. Most studies did not report on power estimations. Ten studies had not identified or adjusted for potential confounders [33, 34, 49–51, 58, 70, 74, 77, 81]. Smoking habits, indoor air pollution, proximity to roads, socio-demographic factors were some of the confounders identified and adjusted for in the study design or data analysis in most studies. Most of the studies used statistical models to measure the association between exposure and health outcomes.

Discussion

In this review, we observed mixed results. In some studies, there was an association between exposure to air pollutants, namely NO_x, SO_2, and $PM_{2.5}$ from CFPPs and increases in the prevalence of respiratory symptoms and diseases and reduced pulmonary function among people living in proximity to CFPPs [46, 47, 61, 69, 76, 78, 81, 84, 86]. On the other hand, Goren et al. [63] and Quizon et al. [77] reported low levels of air pollutants in the study area near CFPPs and that respiratory symptoms were not linked to air pollution from CFPPs. Interestingly, recent studies show that low $PM_{2.5}$ and NO_2 levels (<12 µg/m^3 and <53 part per billion, respectively) may also have negative health effects [88, 89]. Inhaled NO_2 interacts and damages the lung lining fluid and epithelial cell membrane; PM_{10} deposits mainly on the tracheobronchitis region while $PM_{2.5}$ settles on the pulmonary region, penetrates the alveoli, and enters the bloodstream [90–92]. The findings suggest that long-term exposure to air pollution from CFPPs reduced lung function and increases the risk of developing chronic respiratory diseases. Maternal exposure to $PM_{2.5}$ and SO_2 near CFPPs was associated with preterm birth and low birth weight of their neonates [59, 64, 74]. Higher exposure to $PM_{2.5}$ and SO_2 was reported in the first trimester. Furthermore, exposure to SO_2 was linked to shorter gestation times [74]. Inhaled $PM_{2.5}$ and SO_2 can move through the mother's lungs into bloodstream and enter the placenta. This can induce oxidative stress and inflammatory response in mothers and restrict foetal growth [93].

Several studies have shown an association between air pollution and infant mortality [94–97]. Infants and children are particularly vulnerable to air pollution as their lungs are smaller and still developing. A study on the effects of CFPPs on infant mortality rates reported that a 1 GW increase in coal-fired capacity increased infant mortality by 19.3 % in urban areas ($p<0.05$) [50]. In other studies, exposure to PAHs, Hg, Pb, PM_{10} and other air pollutants was linked to neurodevelopmental disorders such as reduced cognitive control, developmental delays and intellectual quotient (IQ) test scores [36, 42, 79]. Exposure to PAHs, Hg, Pb, PM_{10} and other air pollutants was also linked to behavioural issues such as affective problems, anxiety problems, attention deficit hyperactivity disorder, depressive symptoms and social problems [44, 45, 85]. Prenatal exposure to PM was associated with reduced composite cognitive scores in children where PM was thought to induce neuroinflammation and oxidative stress processes [98]. Previous studies also show a link between heavy metals, cognitive abilities, IQ and infant development [99, 100]. The blood-brain barrier develops *in utero*, therefore heavy metals can freely enter the brain and stunt development [99]. Blanchard et al. [52] observed that the prevalence rate of autism was greater in geographic areas of higher Hg levels. Evidence shows that high levels of toxic metals are associated with autism [101]. The number of CFPPs in an area increases the chances of incidence of anaemia in young children [60].

A few studies investigated the association between the prevalence of disease and proximity of communities to CFPPs. CFPPs release air pollutants through smokestacks which are vertical pipes or chimneys. The air pollutant dispersion is dependent upon the wind speed and direction. The air pollutants can travel from an upwind emission source to a downwind location [102]. If the wind is blowing from the west, then as the emissions come off the smokestacks, they will blow and spread towards the east (downwind). Communities living downwind of the CFPP will experience higher exposure to air pollution compared to those located 'upwind'. The United States Environmental Protection Agency (U.S. EPA) recently issued the "Good Neighbor" rule to restrict emissions from CFPP that burdens downwind areas with air pollution [103]. Also, another U.S. EPA report indicates that millions of Americans live within a 3-mile (~5 km) radius of CFPPs thus are vulnerable to health burdens [104]. Our findings show that women who lived closer to CFPPs or downwind from CFPPs at the first and third trimester of pregnancy had increased odds of adverse birth outcomes compared to those who were further away [64, 83]. The most common distance of exposure to air pollution studied was between 0 and 20 km from the CFPP [33–47, 53, 55, 61, 63–65, 67, 69–72, 74, 75, 79, 82, 85] with control sites located at a distance above 20 km from CFPP [65, 67, 68, 70, 75].

Several studies evaluated the health benefits of the closure or retirement of CFPPs. A significant reduction in asthma-related emergency department visit, preterm births, improvement in child neurodevelopment and physical development was reported [35, 37–40, 53, 54, 71, 72, 82]. Previous studies have estimated the health benefits of decommissioning or closure of CFPPs [105, 106]. A study in China showed that the reduced operation of CFPPs during the COVID-19 pandemic lockdown resulted in lower levels of NO_2, PM_{10} and $PM_{2.5}$ (lower by 1.54 μg/m^3, 3.73 μg/m^3 and 2.22 μg/m^3, respectively) [107]. Another study found that elimination of emissions from CFPPs could prevent more than 53,200 premature deaths each year in USA [108]. Similarly, Fan and Wang [62] report that 1 μg/m^3 reduction in $PM_{2.5}$ led to a 3.6 % decrease in mortality in adults older than 65 years after the retirement of CFPPs in USA. The delays in the phasing out of coal for electricity generation and transitioning to cleaner energy sources have been due to concerns such as possible power shortages, increases in electricity price and economic impact [109]. The Just Energy Transition addresses these challenges, particularly in countries where there is a high coal dependency for power generation. A just energy transition ensures that there is fair distribution costs and benefits of the shift of the energy sector from coal to renewables [110]. Local communities will have cleaner air to breathe, improve health and this will in turn reduce the burden on the healthcare system.

Retrofitting the CFPPs with emission control technologies have been to be effective in reducing emissions [111, 112]. Reduction in exposure to air pollution from CFPPs has been reported after the installation of SO_2 emission control systems [53, 82]. In the U.S., the Clean Air Act Amendments require CFPPs to install flue-gas desulfurization units or scrubbers to reduce SO_2 emissions. The scrubbers (wet and dry) are reported to have additional benefits of reducing Hg and particulate matter. Similarly, the European Union adopted the Best Available Technique standards for the energy sector which refer to the use of most economically and technically viable techniques to reduce emissions and impact on the environment [113]. Previous studies show that the implementation of the air quality law and standards, and installation of clean technologies led to improved air quality [114, 115]. This can be one of the strategies to reduce CFPP emissions and health impacts.

It is important to recognize that there is some difficulty and uncertainty in defining proximity and estimating exposure to air pollutants from CFPPs could bias the investigation of the health impacts of CFPPs. The spatial dispersion of air pollutants is not only affected by proximity but also by wind speed, direction, and other meteorological factors [116]. Moreover, population exposures does not necessarily reflect variations in individual exposures to environmental risk factors. Therefore, it is important for future research to improve more precise exposure measures, such as wearable mobile devices for individual participants, and to collect data on long-term exposure, if not lifetime exposome, to environmental toxicants.

We found that most studies used statistical models to measure the association between exposure and health outcomes. While a variety of regression models were used, we recommend that spatial statistical methods (such as spatial regression or geographically weighted regression) should also be used in the future. The existence of spatial dependence or autocorrelation or spatial heterogeneity could bias the estimates of regression parameters when examining the impacts of proximity/exposure to CFPPs.

This scoping review strictly followed the guidelines for conducting such a review and therefore, the findings are deemed reliable. A limitation of the study is that in our quality assessment, we did not exclude studies that were of low quality. However, we highlighted key issues or problems in the study design and other aspects of the studies. Confounders distort the exposure and health outcome association. This review did not explore the impact of confounders, but reported on studies that did not adjust for confounders in the study design.

Conclusions

The findings from this scoping review highlight the evidence showing the health impacts associated with living in proximity to CFPPs. There are limited epidemiological studies in low- and middle-income countries which may warrant attention. Children and pregnant women were among the most studied population groups. There was a statistically significant association between distance from CFPPs and increased odds of respiratory disorders, preterm birth and low birth weight, increased risk of foetal or child development and neurodevelopment problems. It is important to note that other sources of air pollution in the areas near CFPPs may have also contributed to air pollution-related health impacts. More cohort studies covering a larger geographical area to fully display the health impacts of air pollution from CFPPs. Emissions control and the closure or retirement of CFPPs can reduce exposure to air pollution and negative health impacts. Policies that seek to reduce air pollution from CFPPs need to be implemented as we move towards phasing out coal from electricity generation.

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