REPORT

Literature Review: Public Health and Ecological Effects of Substances Emitted to Air from Power Plants

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Submitted to:

Katie Duffett, Project Manager, Clean Air Strategic Alliance

9915-108 Street NW, 1400
Edmonton, Alberta
T5K 2G8

Submitted by:

Golder Associates Ltd.

Suite 200 - 2920 Virtual Way, Vancouver, British Columbia, V5M 0C4, Canada

+1 604 296 4200

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Executive Summary

Golder Associates Ltd. (Golder) was retained by the Clean Air Strategic Alliance (CASA) to conduct a literature review on the public health and ecological effects of substances known to be emitted into the air from electricity generation using various resource types (e.g., coal, biomass, fuel oil, waste) from power plants (not limited to stack emissions). The objective of the literature review was to identify new information published from 2013 to 2020 to aid the 2018 Five-Year Review of the 2003 Emissions Management Framework for Alberta Electricity Sector.

Golder conducted a search of white and grey literature for the literature review. White literature included primary peer-reviewed journal articles while grey literature included literature published by provincial, federal, and international organizations. Relevant articles were scored using the '*Checklist for assessing the quality of quantitative studies*' (herein referred to as the "Checklist") developed at the Alberta Heritage Foundation for Medical Research[1].

The literature review focused on the substances listed in the following categories, as provided in APPENDIX A:

- Category 1: Priority List
- Category 2: Management Actions Need to be Considered
- Category 3: Ongoing Surveillance

Category 4 substances were not included in the scope of work. The literature search was limited to public health and ecological effects, which considered both effects to biotic (e.g., vegetation and wildlife) and abiotic media (e.g., surface water, soil, and air). Based on the data gaps identified in previous Five-Year Reviews, the literature search also considered public health and ecological effects associated with the following:

- new substances or groups of substances (i.e., substances not listed in Categories 1, 2, 3, or 4);
- effects of mixtures;
- effects of low doses over long periods of time; and
- long- and short-range dispersion and deposition.

From the white literature search, 47 articles were identified for evaluation and ranking. Of these white literature studies, one was related to ecological endpoints, while the remainder evaluated human health effects. Five reports were identified in the grey literature and were retained for evaluation and ranking. Four of these reports were related to human health effects from energy generating facilities and evaluated effects of mixtures. One report evaluated the health effects of particulate matter (PM, particles ≤2.5 microns [$PM_{2.5}$] and particles

[1] Kmet LM, Lee RC, Cook LS. 2004. Standard quality assessment criteria for evaluating primary research papers from a variety of fields. AHFMR, Edmonton, Canada.

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≤10 microns [PM_{10}]) and ozone (O_3), separately. A significant amount of effort was put into carrying out the grey literature searches and in the end, only five were retained for evaluation and ranking. The majority of grey literature articles were not original studies or contained information that generalized the health effects of substances without specific reference to studies. Golder recommends that future literature reviews focus on peer-reviewed white literature.

Studies retained for evaluation were related to Category 1 substances (PM, mercury (Hg), nitrogen dioxide [NO_2], sulphur dioxide [SO_2], and O_3), Category 2 metals, and Category 3 metals and polycyclic aromatic hydrocarbons (PAHs). For Category 1 substances, studies retained for evaluation included both human health risk assessments and studies focusing on specific health endpoints (e.g., respiratory effects, diabetes occurrence). Studies retained for evaluation for Category 2 and 3 substances were generally human health risk assessments evaluating the likelihood of increased incremental lifetime cancer risk. It is noted that for Category 2 and 3 metals, studies retained for evaluation often considered multiple metals, however effects and risks were individually assessed for each metal in the study. As a result, some studies are summarized for multiple substances.

Of the ecological studies reviewed, the majority focused on evaluating absorption and uptake of various substances emitted into the air from electricity generation by vegetation species. These studies outlined the relative concentrations of substances emitted into the air from electricity generation-related sources in vegetation but did not evaluate ecological health endpoints (e.g., reduced growth) in vegetation.

No studies were identified in relation to new substances (i.e., substances not listed in Category 1, 2, 3 or 4). Two white literature and three grey literature studies were identified related to the effect of mixtures. Two white literature and two grey literature studies examined the effect of low doses over long periods. No studies were identified related to the public health or ecological effects of long- and short-range dispersion and deposition from substances listed in Categories 1, 2, 3 emitted into the air from electricity generation, however a number of studies related to the topic of effects of long- and short-range dispersion and deposition were identified.

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Acronyms and Abbreviations

Acronym	Definition
CCME	Canadian Council of Ministers of the Environment
CASA	Clean Air Strategic Alliance
Category 1	Priority list substances that are known to be an issue, and known ways of managing them exist and are being employed. (i.e., existing priority substances for which there is insufficient evidence for removal from the list.)
Category 2	Substances that need to be evaluated for further management actions
Category 3	Ongoing surveillance substances that are considered with the express purpose of watching for potential emissions trends over time, and identifying data gaps.
Category 4	Substances for which there is insufficient evidence to indicate that action is required.
Checklist	Checklist for assessing the quality of quantitative studies
CO	carbon monoxide
EBSCO	Elton B. Stephens Company Discovery Service
Ecological	Ecological – for the purposes of this report, ecological refers to both: ■ Biota: the plant and animal life in an ecosystem; and ■ Abiota: non-living chemical and physical factors in an ecosystem (examples include soil, water, air, temperature)
EIP	Environmental Integrity Project
EPRI	Electric Power Research Institute
GHG	greenhouse gases
Golder	Golder Associates Ltd.
Hg	mercury
NO_2	nitrogen dioxide
NO_x	nitrogen oxides
O_3	ozone
OEHHA	California Office of Environmental Health Hazard Assessment
PAHs	polycyclic aromatic hydrocarbons
PM	particulate matter
PM_{10}	particulate matter, with a diameter of 10 micrometres or less
$PM_{2.5}$	particulate matter, with a diameter of 2.5 micrometres or less
SO_2	sulphur dioxide
TEF	Toxic equivalency factor
US EPA	United States Environmental Protection Agency
URL	Uniform Resource Locator

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1.0 INTRODUCTION

Golder Associates Ltd. (Golder) was retained by the Clean Air Strategic Alliance (CASA) to conduct a literature review on the public health and ecological effects of substances known to be emitted into the air from electricity generation using various resource types (e.g., coal, biomass, fuel oil, waste) from power plants (not limited to stack emissions). The objective of the literature review was to identify new information to aid the 2018 third Five-Year review of the 2003 Emissions Management Framework for Alberta Electricity Sector. The literature review focused on new information published from 2013 to 2020.

In 2003, CASA developed a management framework for air emissions resulting from electricity generation in Alberta[2]. The framework is formally reviewed every five years to confirm relevance with new science, technologies, and policies. The Five-Year Reviews are used to inform updates to emission standards for previously assessed substances, develop emission standards for new substances and evaluate the efficacy of the framework in achieving emission management targets.

2.0 SCOPE OF WORK

Golder conducted a search of white and grey literature for the literature review. White literature includes primary peer-reviewed journal articles while grey literature includes literature published by provincial, federal, and international organizations (sources listed in Sections 3.1 and 3.2). The literature review focused on the substances listed in the following categories:

- Category 1: Priority List
- Category 2: Management Actions Need to be Considered
- Category 3: Ongoing Surveillance

Category 4 substances (i.e., substances for which there is insufficient evidence to indicate that action is required) were not included in the scope of work. A list of substances in each category is provided in Appendix A. The literature search of new information (published from 2013 to 2020) included substances listed in the above categories, as well as a 'high level' review of new information since 2013 on new substances or groups of substances emitted into the air by electricity generation (i.e., substances not listed in Categories 1, 2, 3, or 4). The literature search included public health and ecological effects, which considered both effects to biotic (e.g., vegetation and wildlife) and abiotic media (e.g., surface water, soil, and air). Based on the data gaps identified in previous Five-Year Reviews, the literature search also considered public health and ecological effects associated with the following:

- effects of mixtures (i.e., effects that are not specific to only one chemical);
- effects of low doses over long periods of time; and
- long- and short-range dispersion and deposition.

[2] Clean Air Strategic Alliance (CASA) Electricity Project Team. 2003. An Emissions Management Framework for the Alberta Electricity Sector Report to Stakeholders. Edmonton, AB.

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For effects of low doses over long periods, Golder has interpreted that this refers to the evaluation of chronic exposures, defined by Health Canada[3] as greater than 90 days.

The results of the literature review are presented herein.

3.0 SEARCH METHODOLOGY

The literature review focused on public health and ecological effects of substances or groups of substances listed in Categories 1, 2, and 3 and new substances or groups of substances known to be emitted into the air from electricity generation (i.e., not included as a Category substance) published from 2013 to 2020. Public health and ecological effects of Category 1, 2, and 3 substances were also considered within the context of the following data gaps:

- effects associated with mixtures;
- effects associated with exposure to low doses over long periods of time; and
- effects associated with long- and short-range dispersion and deposition.

In general, searches were conducted for the specific Category 1, 2, and 3 substances considering the data gaps listed above. In addition, separate searches were conducted to target the data gaps and potential literature related to new/emerging substances not listed in Category 1, 2, 3, or 4. The list of substances in each category is provided in APPENDIX A.

3.1 White Literature

The white literature search methodology was developed using the Elton B. Stephens Company (EBSCO) Discovery Service (hereafter referred to as “EBSCO”) database for white literature. A summary of the white literature search method is provided below.

The EBSCO database was used to search for peer-reviewed literature published between 01 January 2013 and 31 December 2020. The EBSCO database is a comprehensive search tool that integrates searching of content from subscription databases as well as over 10,000 partner databases including ScienceDirect, MedLine, and Journal Storage (JSTOR). EBSCO provides metadata on publications whether Golder subscribes to the journal or not, with publishers including Elsevier, Wiley, Springer, Taylor & Francis, Sage, Nature Publishing, Association for Computing Machinery (ACM), Oxford, Cambridge, and thousands more.

A stacked search strategy was implemented to yield more targeted primary literature results. A stacked search allows the searcher to combine, exclude, and save different search terms. In this case, search terms were generated specific to the industry, energy type, receptor, substance category, and data gap and were stacked (i.e., combined or excluded) depending on substance and number of search results (APPENDIX B Table B1). Search terms were generated in consideration of the search terms used for previous Five-Year Reviews (Intrinsik

[3] Health Canada. 2010. Federal Contaminated Site Risk Assessment in Canada, Part V: Guidance on Human Health Detailed Quantitative Risk Assessment for Chemicals ($DQRA_{Chem}$). September 2010. Contaminated Sites Division, Safe Environments Directorate.

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2014[4], Leblanc 2014[5]). Search terms for each category were combined using various operators (i.e., OR, AND, * [wildcard], and parentheses). The asterisk wildcard was used to search for words with more than one potential ending. For example, searching for the term tox* would find words toxicity, toxicology, toxicokinetic and any other words that began with "tox". Parentheses were used to nest search terms and the order in which they were interpreted by the search engine. For example, the search terms (power OR energy) AND generation yielded results that contained the phrases "power generation" or "energy generation".

Depending on the number of search results, search terms were applied to 'All text' or the 'Title' fields for a more or less stringent search. For example, when searching in the 'All text' field, more search results were generated when compared to searching for a specific term in the 'Title' field. Search terms were stacked and combined using 'AND' to generate the preliminary set of journal articles. Details on the stacked search terms, operators, and fields are listed in APPENDIX B Table B1. As an internal quality control/quality assurance check, a follow-up Google Scholar based search was conducted for a subset of searches to determine the effectiveness and precision of the EBSCO-based search strategy. Results of the Google Scholar search indicated the EBSCO search method returned a more precise list of results. Overall, the EBSCO search method was considered effective for the white literature search.

Once the initial searches were conducted, the preliminary article outputs were screened by title to evaluate their relevance. For the articles that were retained, the abstract was reviewed as described in Section 3.3 below. For the abstracts that were retained, the articles were evaluated according to the methods described below in Section 3.3. In most cases, the full text of the article was required for evaluation. If the full text articles were not available through EBSCO or internal subscriptions, the articles were purchased.

3.2 Grey Literature

Grey literature includes information published by provincial, federal, and international agencies. The grey literature searches were conducted using the Google search engine (Google.com); however, a subset of agency websites was also searched directly using the agency-specific search engine. The list of agency websites that were searched directly is provided below. A list of agencies searched using the Google search engine is provided in APPENDIX B Table B2.

Grey literature searches were conducted using the website-specific search bar for the following agencies:

- Agency for Toxic Substances and Disease Registry
- California Air Resources Board
- California Office of Environmental Health Hazard Assessment
- Canadian Council of Ministers of the Environment
- Electric Power Research Institute (EPRI)
- Energy Information Administration

[4] Intrinksik. 2014. Final Report – Identification of Ecological Effects of Air Emissions Associated with Electricity Generation: A Literature Search. Prepared for Clean Air Strategic Alliance. May 26, 2014.

[5] Leblanc, Adrienne. 2014. Thermal electricity generation: Atmospheric emissions and associated health effects – Literature review for 2008-2013. Prepared for Clean Air Strategic Alliance Electricity Project Team. May 2014.

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- United States Environmental Protection Agency (US EPA)
- New York State Energy Research and Development Authority
- Texas Commission on Environmental Quality
- World Health Organization

The targeted website searches were selected for agencies which were expected to have the most relevant grey literature and based on a recommendation from a previous literature review[6]. The agency websites were searched using a simplified combination of substance names (i.e., from Categories 1, 2, and 3) and the following search terms:

- health effects OR health impacts
- environmental effects of power plants OR environmental impacts of power plants
- electrical generation
- biomass
- thermal power plants
- coal-fired power plants
- natural gas power plants

Separately, the Google-based grey literature search was conducted using Google and a search term targeted for specific agency Uniform Resource Locators (URLs; APPENDIX B Table B2). For the substance-specific searches (i.e., Category 1, 2 and 3 substances), the same search terms and operators were used for the grey literature search as the white literature search (APPENDIX B Table B1). The following components were combined (with AND) for the Google-based grey literature searches:

- "Agency Specific URL" – See list in APPENDIX B Table B2
- (substance-specific term or data gap specific term) – See list in APPENDIX B Table B1
- (air OR emission*)
- ("coal" OR "natural gas" OR "wind" OR "biomass" OR "solar" OR "fuel" OR "energy")

[6] Intrinksik. 2014. Final Report – Identification of Ecological Effects of Air Emissions Associated with Electricity Generation: A Literature Search. Prepared for Clean Air Strategic Alliance. May 26, 2014.

Results of the grey literature searches were reviewed and only retained if their publication date was between 2013 and 2020. Sources that provided a general summary of health effects but did not present findings from an original study or did not cite the original study, were excluded. Studies that evaluated health effects from oil and gas supply chain emissions including processing, transmission, storage, and distribution were excluded.

Grey literature was evaluated using the same method as white literature (see Section 3.3).

3.3 Evaluation of Identified Studies

Potentially relevant articles, identified by the title search outlined in Sections 3.1 and 3.2, were initially evaluated through an abstract review. Only those studies with apparent relevance to the project were scored using the '*Checklist for assessing the quality of quantitative studies*' (herein referred to as the "Checklist") developed at the Alberta Heritage Foundation for Medical Research[7]. A study was deemed relevant if the information provided in the abstract specifically mentioned or suggested inclusion of information on health effects from substances listed in Categories 1, 2, 3 or new substances (i.e., substances not listed in Categories 1, 2, 3, or 4) emitted into the air by electricity generation. The Checklist is a general tool that allows for a wide variety of study types to be evaluated for 14 categories of technical quality. The same Checklist was used for evaluating studies in a previous Five-Year Review (LeBlanc 2014[8]). For this literature review, the Checklist was expanded to include three entries addressing the data gaps identified in previous Five-Year Reviews:

- effects associated with mixtures;
- effects associated with exposure to low doses over long periods of time; and
- effects associated with long- and short-range dispersion and deposition.

Abstracts did not provide sufficient detail for completion of the Checklist; therefore, full articles were reviewed. Full articles which were not publicly available for download were purchased.

Studies evaluated using the Checklist were scored based on the degree to which each of the 14 technical quality criteria were met, with the final score calculated by dividing the total number of points scored by the total points possible. Studies were also reviewed for presence and/or absence of the three data gaps listed above; however, these checks did not contribute to the scoring calculation. The Checklists for the studies retained for the literature review are provided in APPENDIX C. The references, URLs and abstract of the studies for which Checklists were completed are provided in APPENDIX E.

Based on the Checklist scores, the quality of each study was classified as weak, moderate or strong based on the ranking system determined by Squires et al.[9]. Study quality was considered to be weak (i.e., of low quality) if the

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7 Kmet LM, Lee RC, Cook LS. 2004. Standard quality assessment criteria for evaluating primary research papers from a variety of fields. AHFMR, Edmonton, Canada.

8 Leblanc, Adrienne. 2014. Thermal electricity generation: Atmospheric emissions and associated health effects – Literature review for 2008-2013. Prepared for Clean Air Strategic Alliance Electricity Project Team. May 2014.

9 Squires JE, Hutchinson AM, Bostrom AM, O'Rourke HM, Cobban SJ, Estabrooks CA. 2011. To what extent do nurses use research in clinical practice? A systematic review. Implementation Science 6:21. Available at http://www.implementationscience.com/content/6/1/21.

total calculated score was ≤50%, moderate-weak if the total calculated score was 51-65%, moderate-strong if the total calculated score was 65-79%, and strong (i.e., of high quality) if the total calculated score was ≥80%.

3.4 Evaluation of Uncertainty

Title searches were limited to a discrete number of databases (i.e., for white literature) and websites (i.e., for grey literature). The databases/websites reviewed were selected based on scientific merit and content, and are therefore considered to be an appropriate selection for search completion. It is also noted that the literature search is limited by the capabilities of the databases and search engines used. The searches were further limited to studies and articles which are publicly available, and available in English. These constraints were not considered to hinder the literature search based on the number of relevant studies which were identified. Efforts were taken to limit potential uncertainty (e.g., the uncertainty associated with not identifying a relevant article using the approach documented above) by cross-checking a limited number of EBSCO searches against Google results and reference lists in grey literature reports. This method of cross-checking helped identify if articles were missed using the EBSCO-based white literature search, and provided support for the EBSCO-based search strategy.

Based on the large number of search results using the methodology described in Sections 3.1 and 3.2, studies were initially evaluated based on the title of the studies and/or articles alone. It was not feasible within the confines of the scope of work for this project to review every search result (2,273 for white literature and 175 for grey literature) in detail; therefore, a title review was considered to be a reasonable first step for identifying potentially relevant studies.

The title, abstract, and detailed review of available studies and articles were conducted by a team of experienced environmental scientists and risk assessors familiar with conducting literature reviews.

4.0 SUMMARY OF FINDINGS

The following section provides a high-level summary of the key findings of the literature review. The studies selected for evaluation reported on topics of human health and/or ecological effects from emissions of Category 1, 2, or 3 substances associated with electricity generation. A discussion of findings related to new substances not currently categorized is provided in Section 4.6 and a summary of information related to the data gaps identified in the previous Five-Year Reviews is provided in Section 4.7.

Substances for which new literature was identified are provided in Table 1. No new literature was identified related to human health or ecological health effects for the substances listed below in Table 2.

Table 1: Substances for which new literature was identified

Category	Substance
Category 1	PM, Hg, SO_2, NO_2, GHGs
Category 2	Arsenic, barium, cadmium, cobalt, lead, manganese, chromium (III and VI)
Category 3	Copper, strontium, thallium, zinc, nickel, vanadium, PAHs

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Table 2: Substances for which no new literature was identified

Category	Substance
Category 2	Antimony, selenium, formaldehyde, benzene, hydrogen fluoride
Category 3	Boron, calcium, chlorine, iron, magnesium, molybdenum, potassium, rubidium, silicon, silver Sodium, thorium, titanium, uranium, zirconium, aluminum, beryllium, bromine, phosphorus, hydrogen chloride, ammonia, sulphuric acid, 5-methylchrysene, 7,12-dimethylbenz(a)anthracene, 2-chloroacetophenone, 2,3,7,8-tetrachlorodibenzodioxin and 2,3,7,8-tetrachlorodibenzofuran, 2,4-dinitrotoluene, 3-methylcholanthrene, acetaldehyde, acrolein, benzyl chloride, bis(2-ethylhexyl)phthalate, ethylbenzene, hexachlorobenzene, propylene oxide

4.1 White Literature Summary

Based on the search methodology outlined in Section 3.1, a total of 399 articles were initially identified based on a title search. Following abstract review, 47 articles were retained for evaluation and ranking and summarized below. Of the studies retained for evaluation, only one was related to ecological endpoints, while the remainder evaluated human health effects. Studies retained for evaluation were related to Category 1 substances (particulate matter [PM], mercury, nitrogen dioxide [NO_2], sulphur dioxide [SO_2]), Category 2 metals, and Category 3 metals and polycyclic aromatic hydrocarbons (PAHs).

For Category 1 substances, studies retained for evaluation included both human health risk assessments and studies focusing on specific health endpoints (e.g., respiratory effects, diabetes occurrence). Studies retained for evaluation for Category 2 and 3 substances were generally human health risk assessments evaluating the likelihood of increased incremental lifetime cancer risk. It is noted that for Category 2 and 3 metals, studies retained for evaluation often considered multiple metals; however, effects and risks were individually assessed for each metal in the study. As a result, some studies were included in the summaries for more than one substance.

Of the studies rejected following abstract review, the following is of note:

- Of the ecological studies reviewed, the majority of studies focused on evaluating absorption and uptake of various substances emitted into the air from electricity generation by vegetation or animal species. These studies outlined the relative concentrations of substances from electricity generation-related emissions in vegetation or animals but did not evaluate ecological health endpoints (e.g., reduced growth in vegetation), and were not retained for evaluation.
- Multiple studies evaluated emission characteristics of various substances associated with electricity generation. These studies were not retained for further evaluation and ranking based on a lack of discussion of health effects; however, some of these studies may be relevant for addressing data gaps related to long-range dispersion/deposition of substances. Such dispersion/deposition articles are discussed in Section 4.7.
- Other common themes of studies excluded from evaluation were related to investigations into efficacy and/or efficiency of energy generation processes and efficacy of novel and existing emission control techniques. As per studies related to emission characteristics, these studies were not evaluated due to a lack of information about health effects.

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- A number of studies were found to be related to health effects from residential exposure to emissions such as wood and coal burning within the home, and these were not evaluated due to a lack of relevance to electricity generation-related emissions. Similarly, studies related to health effects from emissions due to solder, gun ranges, cement plants, manufacturing plants and sources other than electricity generation were not evaluated.
- Studies focused on early stages of energy generation such as natural gas locating, drilling and well development or coal mining, rather than end-stage energy production (e.g., biomass burning) were not evaluated. It was noted during the title and abstract review that studies on the health effects related to coal mines (e.g., exposure to dust from coal mines, exposure to run-off water from coal mine waste pits) were common.
- Some health-related studies were focused on topics of health costs or relative toxicity of one substance compared to another (e.g., PAHs), but did not include a discussion of health endpoints (e.g., respiratory effects, increased mortality). These studies were not retained for further evaluation.
- Numerous studies included an evaluation of human and/or ecological risks in urban areas subject to multiple sources of emissions (e.g., vehicular exhaust, residential biomass burning, industrial/manufacturing emissions and power generation emissions). While such studies included electricity generation within their study areas, health risks were evaluated based on exposure to total emissions in the study area; therefore, it was not possible to determine whether health effects were directly correlated with electricity generation. These studies were not retained for further evaluation unless it could be determined that electricity generation were a major source of emissions in the evaluation.
- A number of studies included an evaluation of the impact of implemented emission policies on air quality over time. These studies were not retained for further evaluation and ranking based on a lack of information on health effects.

4.2 Grey Literature Summary

Based on the search methodology outlined in Section 3.2, a total of 175 sources (i.e., reports and websites) were identified based on an initial search. Following abstract/summary/conclusion review, 25 reports were reviewed in detail to determine their relevance. Subsequently, five reports were retained for evaluation and ranking. Three of the grey literature reports selected for inclusion were related to human health effects from energy generating facilities and evaluated effects of mixtures. Two reports were related to health effects of PM and ozone.

Grey literature reports were not retained for further evaluation for one or more of the following reasons:

- Health or ecological effects were evaluated for a combination of industrial facilities or other aspects of the energy supply chain (i.e., hydraulic fracturing, oil and gas refineries, etc.).
- No discussion of health or ecological effects.
- Reports or websites summarized health effects but did not report results from an original/primary study or provided broad summaries of health effects that were not necessarily specific to the energy industry.

4.3 Category 1 Substances

4.3.1 Particulate Matter (PM)

Table 3: Key Particulate Matter Studies for Human Health Effects

Author	Year	Title	Ranking(1)
White Literature			
Michalska, Malgorzata; Zorena, Katarzyna; Waz, Piotr; Bartoszewicz, Maria; Brandt-Varma, Agnieszka; Slezak, Daniel; Robakowska, Marlena	2020	Gaseous pollutants and particulate matter (PM) in ambient air and the number of new cases of type 1 diabetes in children and adolescents in the Pomeranian Voivodeship, Poland	Moderate-Strong
Fabio Caiazzo, Akshay Ashok, Ian A. Waitz, Steve H.L. Yim, Steven R.H. Barrett	2013	Air pollution and early deaths in the United States. Part I: Quantifying the impact of major sectors in 2005	Strong
Sears, Clara G.; Sears, Lonnie; Zierold, Kristina M.	2020	Sex differences in the association between exposure to indoor particulate matter and cognitive control among children (age 6–14 years) living near coal-fired power plants.	Strong
Requia, Weeberb J; Adams, Matthew D; Koutrakis, Petros	2017	Association of $PM_{2.5}$ with diabetes, asthma, and high blood pressure incidence in Canada: A spatiotemporal analysis of the impacts of the energy generation and fuel sales	Moderate-Strong
Gao, Meng; Beig, Gufran; Song, Shaojie; Zhang, Hongliang; Hu, Jianlin; Ying, Qi; Liang, Fengchao; Liu, Yang; Wang, Haikun; Lu, Xiao; Zhu, Tong; Carmichael, Gregory R.; Nielsen, Chris P.; McElroy, Michael B.	2018	The impact of power generation emissions on ambient $PM_{2.5}$ pollution and human health in China and India	Strong
Lu, Mengqian; Lin, Bin-Le; Inoue, Kazuya; Lei, Zhongfang; Zhang, Zhenya; Tsunemi, Kiyotaka	2018	$PM_{2.5}$-related health impacts of utilizing ammonia-hydrogen energy in Kanto Region, Japan	Moderate-Strong
Popadić, Désirée; Heßelbach, Katharina; Richter-Brockmann, Sigrid; Kim, Gwang-Jin; Flemming, Stephan; Schmidt-Heck, Wolfgang; Häupl, Thomas; Bonin, Marc; Dornhof, Regina; Achten, Christine; Günther, Stefan; Humar, Matjaz; Merfort, Irmgard	2018	Gene expression profiling of human bronchial epithelial cells exposed to fine particulate matter ($PM_{2.5}$) from biomass combustion.	Moderate-Strong
Grey Literature			
Greenpeace	2015	Human Cost of Coal Power	Moderate-Strong

Notes:
Ranking is based on degree to which information in an article meets specific criteria. Ranking Checklists are presented in APPENDIX C. Total possible score = 28 - (number of "n/a" * 2), where n/a means non-applicable criteria
Studies were considered to be weak (i.e., of low quality) if the total calculated score was ≤50%, moderate-weak if the total calculated score was 51-65%, moderate-strong if the total calculated score was 65-79% and strong (i.e., of high quality) if the total calculated score was ≥80%.
Links to the articles are provided in APPENDIX E.

Human Health Effects

The review of the white literature identified seven human health effects studies specifically evaluating emissions of PM associated with electricity generation. Of the selected studies, three were of high quality and four were of moderate-strong quality.

- A study completed in an industrial area of Poland identified a correlation between the annual average PM_{10} concentration, along with other air contaminants such as SO_2 and carbon monoxide (CO), and Type 1 diabetes in children (Michalska et al. 2020). Type 1 diabetes was correlated to each of these contaminants

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separately, although co-contaminant exposures cannot be ruled out (e.g., synergistic type effects) (Michalska et al. 2020).

- Another study carried out in Kentucky, USA observed that children aged 6 to 14 years exposed to high PM_{10} concentrations indoors due to living close to a coal-fired power plant had an increased likelihood of errors in cognitive control tests, with females possibly being more susceptible (Sears et al. 2020).
- An air quality modelling study based on emissions from the United States, Canada and Mexico estimated that $PM_{2.5}$ emissions from electric power generation (specific technologies used not specified) could result in approximately 52,000 early deaths per year in the United States (Caiazzo et al. 2013).
- A spatiotemporal analysis in Canada suggested increased incidence of Type 1 diabetes, asthma and high blood pressure with increasing $PM_{2.5}$ concentrations over two years in individuals aged 45-64 years and ≥65 years (Requia et al. 2017). The study evaluated incidence of Type 1 diabetes, asthma and high blood pressure with proximity to energy generation locations across Canada, included nuclear, hydro, coal, natural gas, diesel, fuel oil and win energy plants, and fuel sales in the area relative to energy generation locations and health impacts. $PM_{2.5}$ concentrations were correlated with both energy generation and vehicular emissions; health impacts reported in the study are associated with both energy generation and vehicular emissions (Requia et al 2017).
- Modelling studies from China, India and Japan indicated increased mortality and premature deaths associated with $PM_{2.5}$ emissions from power plants (Gao et al. 2018; Lu et al. 2018).
- A laboratory study determined the effect of $PM_{2.5}$ on gene regulation in lung epithelial cells at concentrations consistent with those measured during monitoring at a biomass-fired power generation plant. Using human genome arrays, bioinformatic analysis and immunoblotting, the study found that $PM_{2.5}$ altered the regulation of 175 genes related to cellular development, metabolism, inflammation, tumourigenesis and immune response (Popadić et al. 2018).

The grey literature review identified one human health effects study that evaluated the effects of PM associated with electricity generation.

- Greenpeace (2015) evaluated health impacts associated with the current and projected coal power plant sector in Indonesia. Indonesia’s proposed power sector is expected to introduce 35 gigawatt new power plants, 22,000 megawatts of which would come from coal power generation. Under the existing energy generation scenario, Greenpeace (2015) attributed a total of 6,290 premature deaths to stroke, ischemic heart disease, chronic obstructive pulmonary disease, lung cancer, other cardiovascular and respiratory diseases to $PM_{2.5}$ exposure in adults and lower respiratory infections in children. Greenpeace (2015) predicted the proposed increase in Indonesia’s power generation sector would result in a total of 19,204 premature deaths due to the health impacts listed above.

Ecological Effects

Biotic & Abiotic

No new literature was identified related to ecological health effects.

Classification: Protected A

4.3.2 Mercury (Hg)

Table 4: Key Mercury Studies for Human Health Effects

Author	Year	Title	Ranking(1)
White Literature			
Chen, Chi-Hsin Sally; Yuan, Tzu-Hsuen; Shie, Ruei-Hao; Wu, Kuen-Yuh; Chan, Chang-Chuan	2017	Linking sources to early effects by profiling urine metabolome of residents living near oil refineries and coal-fired power plants	Strong

Notes:
Ranking is based on degree to which information in an article meets specific criteria. Ranking Checklists are presented in Appendix C. Total possible score = 28 - (number of "n/a" * 2), where n/a means non-applicable criteria
Studies were considered to be weak (i.e., of low quality) if the total calculated score was ≤50%, moderate-weak if the total calculated score was 51-65%, moderate-strong if the total calculated score was 65-79% and strong (i.e., of high quality) if the total calculated score was ≥80%.
A link to the article is provided in APPENDIX E.

Human Health Effects

During the literature search, one white literature study related to human health effects from emissions of mercury associated with electricity generation was identified. The selected study was high quality.

- The study compared estimated emission exposure concentrations of PAHs and select metals (vanadium, nickel, copper, arsenic, strontium, cadmium, mercury, thallium) emission exposure concentrations to urine concentrations of these substances in 252 test subjects (children aged 9-15 years and elderly aged >55 years) living near coal-fired power plants (Chen et al. 2017). Both "low" exposure (further distance from homes to power plant; 141 individuals) and a "high" exposure (closer distance from home to power plant; 111 individuals) individuals were evaluated. The study found that "high" exposure subjects had increased urine concentrations of vanadium, nickel, copper, arsenic, strontium, cadmium, mercury, and thallium, along with higher concentrations of urine oxidative stress biomarkers associated with chronic diseases and allergic respiratory diseases, compared to the 'low' exposure subjects (Chen et al. 2017).

Ecological Effects

Biotic & Abiotic

No new literature was identified related to ecological health effects.

4.3.3 Sulphur Dioxide (SO_2)

Table 5: Key Sulphur Dioxide Studies for Human Health Effects

Author	Year	Title	Ranking(1)
White Literature			
Amster, Eric D.; Haim, Maayan; Dubnov, Jonathan; Broday, David M.	2014	Contribution of nitrogen oxide and sulfur dioxide exposure from power plant emissions on respiratory symptom and disease prevalence.	Strong

Classification: Protected A

Author	Year	Title	Ranking[1]
Thongthammachart, Tin; Pimkotr, Krittiya; Jinsart, Wanida	2017	Health risk assessment of nitrogen dioxide and sulfur dioxide exposure from a new developing coal power plant in Thailand.	Moderate-Strong
Shepherd, Mark A.; Haynatzki, Gleb; Rautiainen, Risto; Achutan, Chandran	2015	Estimates of community exposure and health risk to sulfur dioxide from power plant emissions using short-term mobile and stationary ambient air monitoring	Moderate-Strong
Ewald, Ben	2018	The value of health damage due to sulphur dioxide emissions from coal-fired electricity generation in NSW and implications for pollution licenses	Moderate-Weak

Notes:
Ranking is based on degree to which information in an article meets specific criteria. Ranking Checklists are presented in APPENDIX C. Total possible score = 28 - (number of "n/a" * 2), where n/a means non-applicable criteria
Studies were considered to be weak (i.e., of low quality) if the total calculated score was ≤50%, moderate-weak if the total calculated score was 51-65%, moderate-strong if the total calculated score was 65-79% and strong (i.e., of high quality) if the total calculated score was ≥80%.
Links to the articles are provided in APPENDIX E.

Human Health Effects

The review of the white literature identified four human health effects studies specifically evaluating emissions of SO_2 associated with electricity generation. Of the selected studies, one was of high quality, two of moderate-strong quality and one of moderate-weak quality.

- A study analyzed the information provided by 2,244 participants (aged 18 to 75 years) of the European Community Respiratory Health Survey (Amster et al. 2014). The study did not identify a relationship between SO_2 concentrations in ambient air, sourced from an up-wind coal-fired power plant, and prevalence of asthma, chronic obstructive pulmonary disease or respiratory symptoms (i.e., chronic cough, chronic phlegm, nocturnal dyspnea or shortness of breath) in an industrial area of Poland (Amster et al. 2014).
- A risk assessment based on modelled emissions from a proposed coal power plant in Thailand estimated risks for human receptors from 1-hour, 1-day and annual exposure to SO_2 and NO_2. Receptors considered in the study consisted of 14,000 individuals living within 5 kilometres (km) and 20 km of the coal power plant, located at points of interest including villages, schools and hospitals (receptor groups not specified). Daily and annual risks from exposure to SO_2 calculated for the scenarios evaluated were found to be negligible (i.e., hazard quotient <1); however, potential increased risk (i.e., hazard quotient >1) of unspecified adverse health effects from exposure to SO_2 was identified under the 1-hour exposure scenario (Thongthammachart et al. 2017) (See Section 4.3.4 below for NO_2 results).
- Short-term SO_2 concentrations in ambient air were monitored (stationary and mobile monitoring) from three coal-fired power plants in Baltimore, Maryland to calculate 1-minute, 5-minute and 1-hour average concentrations. The study found that average concentrations emitted from the coal-fired power plants were lower than the concentrations at which respiratory symptoms in humans have been observed in clinical studies for healthy asthmatics (Shepherd et al. 2015). A health cost-benefit assessment of SO_2 particles emitted from coal-fired power plants in Sydney, Australia found that the removal of SO_2 particles from ambient air could prevent 104 premature deaths and 112 hospitalizations associated with heart or lung disease annually (Ewald 2018).

Table 6: Key Sulphur Dioxide Studies for Ecological Effects

Author	Year	Title	Ranking(1)
White Literature			
Muyemeki, Luckson; Burger, Roelof; Piketh, Stuart J; Evans, Steven W	2017	Bird species richness and densities in relation to sulphur dioxide gradients and environmental variables	Moderate-Strong

Notes:
Ranking is based on degree to which information in an article meets specific criteria. Ranking Checklists are presented in APPENDIX C. Total possible score = 28 - (number of "n/a" * 2), where n/a means non-applicable criteria
Studies were considered to be weak (i.e., of low quality) if the total calculated score was ≤50%, moderate-weak if the total calculated score was 51-65%, moderate-strong if the total calculated score was 65-79% and strong (i.e., of high quality) if the total calculated score was ≥80%.
A link to the article is provided in APPENDIX E.

Ecological Effects

Abiotic

No new literature retained for evaluation.

Biotic

The literature review identified one biotic ecological effects study specifically evaluating emissions of SO_2 associated with electricity generation. The selected study was of moderate-strong quality.

- A study around a coal-fired power plant in South Africa found that SO_2 levels had no influence on species richness and species density of birds. The SO_2 levels measured within the 50 km radius study area were noted to be below the annual national ambient air quality standards at the locations assessed (Muyemeki et al. 2017).

4.3.4 Nitrogen Dioxide (NO_2)

Table 7: Key Nitrogen Dioxide Studies for Human Health Effects

Author	Year	Title	Ranking(1)
White Literature			
Amster, Eric D.; Haim, Maayan; Dubnov, Jonathan; Broday, David M.	2014	Contribution of nitrogen oxide and sulfur dioxide exposure from power plant emissions on respiratory symptom and disease prevalence.	Strong
Thongthammachart, Tin; Pimkotr, Krittiya; Jinsart, Wanida	2017	Health risk assessment of nitrogen dioxide and sulfur dioxide exposure from a new developing coal power plant in Thailand.	Moderate-Strong

Notes:
Ranking is based on degree to which information in an article meets specific criteria. Ranking Checklists are presented in APPENDIX C. Total possible score = 28 - (number of "n/a" * 2), where n/a means non-applicable criteria
Studies were considered to be weak (i.e., of low quality) if the total calculated score was ≤50%, moderate-weak if the total calculated score was 51-65%, moderate-strong if the total calculated score was 65-79% and strong (i.e., of high quality) if the total calculated score was ≥80%.
Links to the articles are provided in APPENDIX E.

Classification: Protected A

Human Health Effects

The review of the white literature identified two human health effects studies specifically evaluating emissions of NO_2 associated with electricity generation. Of the selected studies, one was of high quality and one of moderate-strong quality.

- A study analyzed the information provided by 2,244 participants (aged 18 to 75 years) of the European Community Respiratory Health Survey. The study identified a relationship between nitrogen oxides (NO_x) concentrations in ambient air, sourced from an up-wind coal-fired power plant, and respiratory symptoms (i.e., chronic cough, chronic phlegm, nocturnal dyspnea or shortness of breath) in an industrial area of Poland (Amster et al. 2014). The study did not identify a relationship between NO_x concentrations in ambient air and prevalence of asthma or chronic obstructive pulmonary disease (Amster et al. 2014).
- A risk assessment based on modelled emissions for a proposed coal power plant in Thailand estimated risks for a human receptors from 1-hour, 1-day and annual exposure to SO_2 and NO_2. Receptors considered in the study consisted of 14,000 individuals living within 5 km and 20 km of the coal power plant, located at points of interest including villages, schools and hospitals (receptor groups not specified). Risks (specific effects unspecified) from exposure to NO_2 for the scenarios evaluated were found to be negligible (i.e., hazard quotient <1) (Thongthammachart et al. 2017) (See Section 4.3.3 above for SO_2 results).

Ecological Effects

Biotic & Abiotic

No new literature was identified related to ecological health effects.

4.3.5 Greenhouse Gases (GHGs)

Table 8: Key Greenhouse Gas Studies for Human Health Effects

Author	Year	Title	Ranking[(1)]
Grey Literature			
Greenpeace	2015	Human Cost of Coal Power	Strong

Notes:
Ranking is based on degree to which information in an article meets specific criteria. Ranking Checklists are presented in APPENDIX C. Total possible score = 28 - (number of "n/a" * 2), where n/a means non-applicable criteria
Studies were considered to be weak (i.e., of low quality) if the total calculated score was ≤50%, moderate-weak if the total calculated score was 51-65%, moderate-strong if the total calculated score was 65-79% and strong (i.e., of high quality) if the total calculated score was ≥80%.
A link to the article is provided in APPENDIX E.

Human Health Effects

The review of the grey literature identified one human health effects study that evaluated the effects of greenhouse gases (O_3) associated with electricity generation. The selected study was considered to be of high quality.

- Greenpeace (2015) evaluated health impacts associated with the current and projected coal power plant sector in Indonesia. Indonesia's proposed power sector is expected to introduce 35 gigawatt new power plants, 22,000 megawatts of which would come from coal power generation. Under the existing energy generation scenario, Greenpeace (2015) attributed a total of 801 premature deaths to respiratory diseases due to ozone exposure in adults. Greenpeace (2015) predicted the proposed increase in Indonesia's power generation sector would result in a total of 2,027 premature deaths due to respiratory diseases due to ozone exposure in adults.

Ecological Effects

Biotic & Abiotic

No new literature was identified related to ecological health effects.

4.4 Category 2 Substances

4.4.1 Arsenic (As)

Table 9: Key Arsenic Studies for Human Health Effects

Author	Year	Title	Ranking(1)
White Literature			
Xue, Qianqian; Jiang, Zhuo; Wang, Xiang; Song, Danlin; Huang, Fengxia; Tian, Yingze; Huang-fu, Yanqi; Feng, Yinchang	2019	Comparative study of PM_{10}-bound heavy metals and PAHs during six years in a Chinese megacity: Compositions, sources, and source-specific risks	Moderate-Strong
Bi, Chenglu; Chen, Yantong; Zhao, Zhuzi; Li, Qing; Zhou, Quanfa; Ye, Zhaolian; Ge, Xinlei	2020	Characteristics, sources and health risks of toxic species (PCDD/Fs, PAHs and heavy metals) in $PM_{2.5}$ during fall and winter in an industrial area	Strong
Yuan T. H.; Pien W. H.; Chan C. C.	2013	Urinary heavy metal levels of residents in the vicinity of a petrochemical complex in Taiwan	Strong
Peng, Hao; Wang, Bao-feng; Yang Feng-ling; Cheng, Fang-qin	2020	Study on the environmental effects of heavy metals in coal gangue and coal combustion by ReCiPe2016 for life cycle impact assessment	Weak
Chen, Chi-Hsin Sally; Yuan, Tzu-Hsuen; Shie, Ruei-Hao; Wu, Kuen-Yuh; Chan, Chang-Chuan	2017	Linking sources to early effects by profiling urine metabolome of residents living near oil refineries and coal-fired power plants	Strong
Liu, Jianwei; Chen, Yanjiao; Chao, Sihong; Cao, Hongbin; Zhang, Aichen; Yang, Yue	2018	Emission control priority of $PM_{2.5}$-bound heavy metals in different seasons: A comprehensive analysis from health risk perspective	Strong

Notes:
Ranking is based on degree to which information in an article meets specific criteria. Ranking Checklists are presented in APPENDIX C. Total possible score = 28 - (number of "n/a" * 2), where n/a means non-applicable criteria
Studies were considered to be weak (i.e., of low quality) if the total calculated score was ≤50%, moderate-weak if the total calculated score was 51-65%, moderate-strong if the total calculated score was 65-79% and strong (i.e., of high quality) if the total calculated score was ≥80%.
Links to the articles are provided in APPENDIX E.

Human Health Effects

The literature review identified six human health effects studies specifically evaluating emissions of arsenic associated with electricity generation. Of the selected studies, four were high quality, one was moderate-strong quality and one was of low/weak quality.

Classification: Protected A

- A risk assessment was completed for Chengdu, a Chinese megacity, which considered atmospheric PM_{10}-bound metals (arsenic, cadmium, chromium, copper, lead, nickel) from multiple sources including gasoline, diesel and coal combustion and other industrial sources. The study found that inhalation non-carcinogenic risks were within acceptable levels for all metals evaluated (i.e., hazard quotients <1). Carcinogenic risks (i.e., incremental lifetime cancer risks) from arsenic and from the sum of all metals evaluated were associated risks above the target level ($1x10^{-5}$ for arsenic and for total metals versus target of $1x10^{-6}$) (Xue et al. 2019). Other air pollutants including PAHs were considered in this study, and industrial sources of metals were considered to be high contributors to overall risk (Xue et al. 2019). It is noted that risks were calculated based on metal concentrations which included contributions from multiple sources other than power plants/energy generation.
- A health assessment completed in an industrial area of Changzhou, a major city in China, evaluated inhalation non-carcinogenic and carcinogenic risks from 14 metals (lead, iron, aluminum, zinc, silver, arsenic, cadmium, cobalt, chromium, copper, manganese, nickel, selenium, vanadium) from multiple sources including vehicular emissions, coal combustion and industrial sources. The study found that carcinogenic risk from exposure to arsenic over a lifetime (70 years) were within acceptable levels (i.e., incremental lifetime cancer risk $<1x10^{-6}$) (Bi et al. 2020). Risks were calculated for children and adults, with results provided for both males and females. Arsenic was determined to be sourced mainly from industrial emissions and coal combustion (Bi et al. 2020).
- A biological monitoring study in Taiwan (Yunlin County) of adult residents living close to a petrochemical complex (naptha cracking, oil refineries, coal-fired power plant) investigated the effects of 10 metals (vanadium, manganese, strontium, arsenic, lead, copper, cadmium, nickel, chromium, thallium). The study examined trends between age, gender and behaviour (i.e., smoking) and urinary levels of the 10 metals, and determined appropriate biomarkers for assessments of similar petrochemical complexes. Increased urinary arsenic levels were found to be correlated with increased age and proximity to the petrochemical complex (Yuan et al. 2013).
- A study of arsenic and lead emissions from coal combustion calculated environmental effect values (i.e., environmental impact scores) for bottom slag, fly ash and flue gas emissions using a life cycle impact assessment software, and found that environmental effects from emissions are higher in air than soil and that the effects of lead are higher than those of arsenic (Peng et al. 2020). The life cycle impact assessment software considers several endpoints related to both human health and the environment (e.g., human toxicity, urban land occupation, water depletion, climate change, ozone depletion, terrestrial and aquatic ecotoxicity, etc.).
- A study in Yunlin County, Taiwan compared estimated emission exposure concentrations of PAHs and select metals (vanadium, nickel, copper, arsenic, strontium, cadmium, mercury, thallium) to urine concentrations of these substances in 252 test subjects (children aged 9-15 years and elderly aged >55 years) living near coal-fired power plants (Chen et al. 2017). Both “low” exposure (further distance from homes to power plant; 141 individuals) and a “high” exposure (closer distance from home to power plant; 111 individuals) individuals were evaluated. The study found that “high” exposure subjects had increase urine concentrations of arsenic, along with higher concentrations of urine oxidative stress biomarkers associated with chronic diseases and allergic respiratory diseases, compared to the “low” exposure subjects (Chen et al. 2017).
- A risk assessment completed for Beijing, a Chinese megacity, which considered atmospheric PM_{10}-bound metals (arsenic, barium, cadmium, cobalt, chromium (VI), manganese, nickel, vanadium) and PM_{10}-bound PAHs evaluated non-carcinogenic and carcinogenic risks from inhalation of these substances in ambient air. Non-carcinogenic risks were calculated to be acceptable for all metals evaluated individually, and for total metals (i.e., hazard quotients <1). The risks for total metals was noted to be near the target risk level (i.e.,

hazard quotient calculated to be 0.89 compared to target hazard quotient of 1) (Liu et al. 2018). Arsenic was determined to be one of the largest contributors to calculated non-carcinogenic risk estimates. Carcinogenic risks for arsenic and for total metals were above the acceptable risk level (i.e., incremental lifetime cancer risks $>1x10^{-6}$) (Liu et al. 2018). Arsenic was the most significant contributor to the calculated cancer risk estimates. Sources of PM-bound metal emissions were determined to be (in decreasing order) chromium-related industry, vehicular emissions, re-suspended dust, copper-related industry and fuel oil and coal combustion (Liu et al. 2018). It is noted that risks were calculated based on metal concentrations from multiple sources, and power plants/energy generation was not the most significant source of emissions.

Ecological Effects

Biotic & Abiotic

No new literature was identified related to ecological health effects.

4.4.2 Barium (Ba)

Table 10: Key Barium Studies for Human Health Effects

Author	Year	Title	Ranking(1)
White Literature			
Liu, Jianwei; Chen, Yanjiao; Chao, Sihong; Cao, Hongbin; Zhang, Aichen; Yang, Yue	2018	Emission control priority of $PM_{2.5}$-bound heavy metals in different seasons: A comprehensive analysis from health risk perspective	Strong

Notes:
Ranking is based on degree to which information in an article meets specific criteria. Ranking Checklists are presented in APPENDIX C. Total possible score = 28 – (number of “n/a” * 2), where n/a means non-applicable criteria
Studies were considered to be weak (i.e., of low quality) if the total calculated score was ≤50%, moderate-weak if the total calculated score was 51-65%, moderate-strong if the total calculated score was 65-79% and strong (i.e., of high quality) if the total calculated score was ≥80%.
A link to the article is provided in APPENDIX E.

Human Health Effects

The literature review identified one human health effects study specifically evaluating emissions of barium associated with electricity generation. The selected study was considered to be high quality.

- Atmospheric PM_{10}-bound metals (arsenic, barium, cadmium, cobalt, chromium (VI), manganese, nickel, vanadium) and PM_{10}-bound PAHs were evaluated to determine non-carcinogenic and carcinogenic risks from inhalation of ambient air in a risk assessment carried out for Beijing, China. Non-carcinogenic risks were calculated to be acceptable for all metals evaluated individually (i.e., hazard quotients <1). The total metal risk was also determined to be acceptable, however, was noted to be near the target risk level (i.e., hazard quotient calculated to be 0.89 compared to target hazard quotient of 1) (Liu et al. 2018). Barium was determined to be the one of most significant drivers of non-carcinogenic risk. Sources of PM-bound metal emissions were determined to be (in decreasing order) chromium-related industry, vehicular emissions, re-suspended dust, copper-related industry and fuel oil and coal combustion (Liu et al. 2018). It is

Classification: Protected A

noted that risks were calculated based on metal concentrations from multiple sources, and power plants/energy generation was not the most significant source of emissions.

Ecological Effects

Biotic & Abiotic

No new literature was identified related to ecological health effects.

4.4.3 Cadmium (Cd)

Table 11: Key Cadmium Studies for Human Health Effects

Author	Year	Title	Ranking(1)
White Literature			
Xue, Qianqian; Jiang, Zhuo; Wang, Xiang; Song, Danlin; Huang, Fengxia; Tian, Yingze; Huang-fu, Yanqi; Feng, Yinchang	2019	Comparative study of PM_{10}-bound heavy metals and PAHs during six years in a Chinese megacity: Compositions, sources, and source-specific risks	Moderate-Strong
Wang, Kun; Wang, Weiye; Li, Lili; Li, Jianju; Wei, Liangliang; Chi, Wanqiu; Hong, Lijing; Zhao, Qingliang; Jiang, Junqiu	2020	Seasonal concentration distribution of PM_{10} and $PM_{2.5}$ and a risk assessment of bound trace metals in Harbin, China: Effect of the species distribution of heavy metals and heat supply.	Strong
Yuan T. H.; Pien W. H.; Chan C. C.	2013	Urinary heavy metal levels of residents in the vicinity of a petrochemical complex in Taiwan	Strong
Cai, Kui; Li, Chang; Na, Sanggyun	2019	Spatial distribution, pollution source, and health risk assessment of heavy metals in atmospheric depositions: A case study from the sustainable city of Shijiazhuang, China	Moderate-Strong
Chen, Chi-Hsin Sally; Yuan, Tzu-Hsuen; Shie, Ruei-Hao; Wu, Kuen-Yuh; Chan, Chang-Chuan	2017	Linking sources to early effects by profiling urine metabolome of residents living near oil refineries and coal-fired power plants	Strong
Liu, Jianwei; Chen, Yanjiao; Chao, Sihong; Cao, Hongbin; Zhang, Aichen; Yang, Yue	2018	Emission control priority of $PM_{2.5}$-bound heavy metals in different seasons: A comprehensive analysis from health risk perspective	Strong

Notes:
Ranking is based on degree to which information in an article meets specific criteria. Ranking Checklists are presented in APPENDIX C. Total possible score = 28 – (number of "n/a" * 2), where n/a means non-applicable criteria
Studies were considered to be weak (i.e., of low quality) if the total calculated score was ≤50%, moderate-weak if the total calculated score was 51-65%, moderate-strong if the total calculated score was 65-79% and strong (i.e., of high quality) if the total calculated score was ≥80%.
Links to the articles are provided in APPENDIX E.

Human Health Effects

The literature review identified six human health effects studies specifically evaluating emissions of cadmium associated with electricity generation. Of the selected studies, four were high quality and two were moderate-strong quality.

Classification: Protected A

- Atmospheric PM_{10}-bound metals (arsenic, cadmium, chromium, copper, lead, nickel) were evaluated in a risk assessment for Chengdu, China. Non-carcinogenic risks (i.e., hazard quotients) were within acceptable levels for all metals evaluated (i.e., hazard quotients <1). Carcinogenic risks (i.e., incremental lifetime cancer risks) from cadmium were marginally above the target risk level ($1.3x10^{-6}$ versus target of $1x10^{-6}$) and risks from the sum of all metals evaluated were associated with above the target level ($1x10^{-5}$ versus target of $1x10^{-6}$) (Xue et al. 2019). Sources of metal emissions in the study were determined to be gasoline, diesel and coal combustion and industrial sources. Industrial sources of metals were considered to be high contributors to overall risk (Xue et al. 2019). It is noted that risks were calculated based on metal concentrations from multiple sources other than power plants/energy generation.
- A risk assessment conducted in Harbin, China calculated average daily doses for children and adults of trace metals bound to PM, considering exposure from ingestion, inhalation and dermal contact. The study found that ingestion was the most significant exposure pathway, followed by dermal contact and then inhalation. Children were found to more exposed than adults via ingestion and dermal contact with PM, while adults were found to be more exposed than children from inhalation. The assessment concluded that cadmium was a significant driver of exposure from all exposure pathways evaluated (Wang et al. 2020). It is noted that emissions in the risk assessment were sourced from both vehicles and power plants.
- Ten metals (vanadium, manganese, strontium, arsenic, lead, copper, cadmium, nickel, chromium, thallium) were evaluated in a biological monitoring study in Yunlin County, Taiwan. The study of adult residents living close to a petrochemical complex (naptha cracking, oil refineries, coal-fired power plant) identified trends between age, gender and behaviour (i.e., smoking) and urinary levels of the 10 metals, and determined appropriate biomarkers for assessments of similar petrochemical complexes. Increased urinary cadmium levels were found to be correlated with increased age and higher in females, and unlike most metals in the study, cadmium urinary concentrations were higher in those living further from the petrochemical complex than those closer to it (Yuan et al. 2013).
- A study of sources, distribution, and health effects from deposition of metals (i.e., cadmium, chromium, copper, lead, nickel and zinc) from atmospheric emissions in Shijiazhuang, a Chinese city, determined that zinc, cadmium and lead emissions deposited to soil were attributable to coal-fired power plants (Cai et al. 2019). The health risk assessment indicated that non-carcinogenic and carcinogenic risks for both children and adults were below the acceptable risk threshold (i.e., hazard quotients <1, incremental lifetime cancer risks $<1x10^{-6}$) for incidental ingestion, dermal contact and inhalation for all metals evaluated (Cai et al. 2019).
- The urine concentrations of several metals (vanadium, nickel, copper, arsenic, strontium, cadmium, mercury, thallium) in 252 test subjects (children aged 9-15 years and elderly aged >55 years) living near coal-fired power plants in Yunlin County, Taiwan were compared to emission concentrations from the power plants (Chen et al. 2017). The study evaluated “low” (further distance from homes to power plant; 141 individuals) and a “high” (closer distance from home to power plant; 111 individuals) exposure individuals. The study found that “high” exposure subjects had increased urine concentrations of cadmium and higher concentrations of urine biomarkers indicative of chronic diseases and allergic respiratory diseases, compared to the “low” exposure subjects (Chen et al. 2017).
- PM-bound metal emissions from (in decreasing order of magnitude) chromium-related industry, vehicular emissions, resuspended dust, copper-related industry and fuel oil and coal combustion were evaluated in a risk assessment for Beijing, China. The study focused on atmospheric PM_{10}-bound metals (arsenic, barium, cadmium, cobalt, chromium (VI), manganese, nickel, vanadium) in ambient air and determined non-

Classification: Protected A

carcinogenic and carcinogenic risks from inhalation (Liu et al. 2018). Non-carcinogenic risks were calculated to be acceptable for the individual metals and for total metals (i.e., hazard quotients <1). However, the total metal risk was noted to be near the target risk level (i.e., hazard quotient calculated to be 0.89 compared to target hazard quotient of 1) (Liu et al. 2018). Cadmium was not determined to be one of the more significant drivers of non-carcinogenic risk. Carcinogenic risks for cadmium were below the target risk level (i.e., $<1x10^{-6}$) however carcinogenic risk for total metals was above the acceptable risk level (i.e., $>1x10^{-6}$) (Liu et al. 2018). It is noted that risks were calculated based on metal concentrations from multiple sources, and power plants/energy generation was not the most significant source of emissions.

Ecological Effects

Biotic & Abiotic

No new literature was identified related to ecological health effects.

4.4.4 Cobalt (Co)

Table 12: Key Cobalt Studies for Human Health Effects

Author	Year	Title	Ranking(1)
White Literature			
Xue, Qianqian; Jiang, Zhuo; Wang, Xiang; Song, Danlin; Huang, Fengxia; Tian, Yingze; Huang-fu, Yanqi; Feng, Yinchang	2019	Comparative study of PM_{10}-bound heavy metals and PAHs during six years in a Chinese megacity: Compositions, sources, and source-specific risks	Moderate-Strong
Wang, Kun; Wang, Weiye; Li, Lili; Li, Jianju; Wei, Liangliang; Chi, Wanqiu; Hong, Lijing; Zhao, Qingliang; Jiang, Junqiu	2020	Seasonal concentration distribution of PM1.0 and $PM_{2.5}$ and a risk assessment of bound trace metals in Harbin, China: Effect of the species distribution of heavy metals and heat supply.	Strong
Liu, Jianwei; Chen, Yanjiao; Chao, Sihong; Cao, Hongbin; Zhang, Aichen; Yang, Yue	2018	Emission control priority of $PM_{2.5}$-bound heavy metals in different seasons: A comprehensive analysis from health risk perspective	Strong

Notes:
Ranking is based on degree to which information in an article meets specific criteria. Ranking Checklists are presented in APPENDIX C. Total possible score = 28 – (number of “n/a” * 2), where n/a means non-applicable criteria
Studies were considered to be weak (i.e., of low quality) if the total calculated score was ≤50%, moderate-weak if the total calculated score was 51-65%, moderate-strong if the total calculated score was 65-79% and strong (i.e., of high quality) if the total calculated score was ≥80%.
Links to the articles are provided in APPENDIX E.

Human Health Effects

The literature review identified three human health effects studies specifically evaluating emissions of cobalt associated with electricity generation. Of the selected studies, two of high quality and one was of moderate-strong quality.

- Carcinogenic risks (i.e., incremental lifetime cancer risks) from cobalt and risks from the sum of all metals (arsenic, cadmium, chromium, copper, lead, nickel) were found to be associated with risks above the target

Classification: Protected A

level ($9x10^{-6}$ to $1x10^{-5}$ for cobalt and for $1x10^{-5}$ total metals versus target of $1x10^{-6}$) in a risk assessment carried out in Chengdu, China (Xue et al. 2019). The risk assessment evaluated inhalation exposure to atmospheric PM_{10}-bound metals. Non-carcinogenic risks (i.e., hazard quotients) were within acceptable levels for all metals evaluated (i.e., hazard quotients <1). The sources of metal emissions in the study were determined to be gasoline, diesel and coal combustion and industrial sources. Industrial sources of metals were considered to be high contributors to overall risk (Xue et al. 2019). It is noted that risks were calculated based on metal concentrations from multiple sources other than power plants/energy generation.

- A study found that ingestion was the most significant exposure pathway for PM-bound metals, followed by dermal contact and then inhalation. The risk assessment was carried out in Harbin, China to calculate average daily doses for children and adults. Ingestion and dermal contact exposure pathways were found to result in higher concentrations in children than adults, and adults were concluded to be more exposed than children from the inhalation exposure pathway. The assessment concluded that cobalt was a significant driver of exposure from all exposure pathways (Wang et al. 2020). It is noted that emissions in the risk assessment were sourced from both vehicles and power plants.
- Atmospheric PM_{10}-bound cobalt, along with other PM_{10}-bound metals (arsenic, barium, cadmium, cobalt, chromium (VI), manganese, nickel, vanadium), were evaluated in a risk assessment completed for Beijing, China. The study evaluated non-carcinogenic and carcinogenic risks from inhalation of these substances in ambient air. For both individual metals and total metals non-carcinogenic risks were calculated to be acceptable (i.e., hazard quotients <1), however the total metal risk was noted to be near the target risk level (i.e., hazard quotient calculated to be 0.89 compared to target hazard quotient of 1) (Liu et al. 2018). Cobalt was not determined to be one of the more significant drivers of non-carcinogenic risk. Carcinogenic cobalt and for total metals were above the acceptable risk level (i.e., cancer risk $>1x10^{-6}$) (Liu et al. 2018). Chromium-related industrial activities, vehicular emissions, resuspended dust, copper-related industry and fuel oil and coal combustion were determined to be the sources of metal emissions in the study, in decreasing order of magnitude (Liu et al. 2018). It is noted that risks were calculated based on metal concentrations from multiple sources, and power plants/energy generation was not the most significant source of emissions.

Ecological Effects

Biotic & Abiotic

No new literature was identified related to ecological health effects.

Classification: Protected A

4.4.5 Lead (Pb)

Table 13: Key Lead Studies for Human Health Effects

Author	Year	Title	Ranking(1)
White Literature			
Pizzol, Massimo; Møller, Flemming; Thomsen, Marianne	2013	External costs of atmospheric lead emissions from a waste-to-energy plant: A follow-up assessment of indirect exposure via topsoil ingestion	Weak
Bi, Chenglu; Chen, Yantong; Zhao, Zhuzi; Li, Qing; Zhou, Quanfa; Ye, Zhaolian; Ge, Xinlei	2020	Characteristics, sources and health risks of toxic species (PCDD/Fs, PAHs and heavy metals) in $PM_{2.5}$ during fall and winter in an industrial area	Strong
Wang, Kun; Wang, Weiye; Li, Lili; Li, Jianju; Wei, Liangliang; Chi, Wanqiu; Hong, Lijing; Zhao, Qingliang; Jiang, Junqiu	2020	Seasonal concentration distribution of PM1.0 and $PM_{2.5}$ and a risk assessment of bound trace metals in Harbin, China: Effect of the species distribution of heavy metals and heat supply.	Strong
Yuan T. H.; Pien W. H.; Chan C. C.	2013	Urinary heavy metal levels of residents in the vicinity of a petrochemical complex in Taiwan	Strong
Peng, Hao; Wang, Bao-feng; Yang Feng-ling; Cheng, Fang-qin	2020	Study on the environmental effects of heavy metals in coal gangue and coal combustion by ReCiPe2016 for life cycle impact assessment	Weak
Cai, Kui; Li, Chang; Na, Sanggyun	2019	Spatial distribution, pollution source, and health risk assessment of heavy metals in atmospheric depositions: A case study from the sustainable city of Shijiazhuang, China	Moderate-Strong

Notes:
Ranking is based on degree to which information in an article meets specific criteria. Ranking Checklists are presented in APPENDIX C. Total possible score = 28 - (number of "n/a" * 2), where n/a means non-applicable criteria
Studies were considered to be weak (i.e., of low quality) if the total calculated score was ≤50%, moderate-weak if the total calculated score was 51-65%, moderate-strong if the total calculated score was 65-79% and strong (i.e., of high quality) if the total calculated score was ≥80%.
Links to the articles are provided in APPENDIX E.

Human Health Effects

The literature review identified six human health effects studies specifically evaluating emissions of lead associated with electricity generation. Of the selected studies, three were of high quality, one was of moderate-strong quality and two were of low quality.

- An impact pathway approach study of a waste-to-energy plant in Copenhagen, Denmark evaluated neurotoxic effects of lead ingested in soil impacted through atmospheric deposition from the plant and found that lead exposure led to diminished cognitive ability (i.e., lower IQ points) in children aged 0-3 years (Pizzol et al. 2013).
- A study which evaluated inhalation non-carcinogenic and carcinogenic risks from metals (lead, zinc, arsenic, chromium, copper, manganese, nickel) found that carcinogenic risks from lead considering a 70-year exposure period were slight above the target risk level (Bi et al. 2020). The study was carried out in Changzhou, China where metal emissions were determined to be related to vehicular emissions, coal combustion, and industrial sources. Risks were calculated for children and adults, with results provided for

Classification: Protected A

both males and females. Lead was found to be mainly sourced from vehicular emissions therefore risks are likely not driven from power plants/energy generation (Bi et al. 2020).

- A risk assessment in Harbin, China concluded that PM-bound lead was a significant contributor of exposure from ingestion, inhalation and dermal contact pathways (Wang et al. 2020). Emissions in the risk assessment were sourced from both vehicles and power plants. The study found that ingestion was the most significant exposure pathway, followed by dermal contact and then inhalation. Inhalation determined to be the most significant exposure pathway for adults while ingestion and dermal contact were found to be the most significant exposure pathway for children.
- Trends between age, gender and behaviour (i.e., smoking) and urinary levels of 10 metals (vanadium, manganese, strontium, arsenic, lead, copper, cadmium, nickel, chromium, thallium) and biomarkers for assessments of petrochemical complexes (including naptha cracking, oil refineries, coal-fired power plants) were determined in a biological monitoring study (Yuan et al. 2013). Increased urinary lead levels were found to be correlated with increased age and higher in females. The study was carried out with adult residents living in close proximity to a petrochemical complex in Yunlin County, Taiwan (Yuan et al. 2013).
- Environmental effect values (i.e., environmental impact scores) for bottom slag, fly ash and flue gas emissions from coal combustion were calculated for arsenic and lead using a life cycle impact assessment software. The program found that environmental effects from emissions are higher in air than soil and that the effects of lead are more significant than those of arsenic (Peng et al. 2020). The life cycle impact assessment software considers several endpoints related to both human health and the environment (e.g., human toxicity, urban land occupation, water depletion, climate change, ozone depletion, terrestrial and aquatic ecotoxicity, etc.).
- A health risk assessment in Shijiazhuang, China determined that non-carcinogenic and carcinogenic risks for both children and adults were below the acceptable risk threshold (i.e., hazard quotients <1, incremental lifetime cancer risks $<1 \times 10^{-6}$) for incidental ingestion, dermal contact and inhalation of soil for all metals evaluated (i.e., cadmium, chromium, copper, lead, nickel and zinc) in the study (Cai et al. 2019). The study assessed risks from contact with soil to which metal emissions from coal-fired power plants had been deposited.

Ecological Effects

Biotic & Abiotic

No new literature was identified related to ecological health effects.

4.4.6 Manganese (Mn)

Table 14: Key Manganese Studies for Human Health Effects

Author	Year	Title	Ranking[(1)]
White Literature			
Bi, Chenglu; Chen, Yantong; Zhao, Zhuzi; Li, Qing; Zhou, Quanfa; Ye, Zhaolian; Ge, Xinlei	2020	Characteristics, sources and health risks of toxic species (PCDD/Fs, PAHs and heavy metals) in $PM_{2.5}$ during fall and winter in an industrial area	Strong
Wang, Kun; Wang, Weiye; Li, Lili; Li, Jianju; Wei, Liangliang; Chi, Wanqiu;	2020	Seasonal concentration distribution of PM1.0 and $PM_{2.5}$ and a risk assessment of bound trace metals in Harbin, China:	Strong

Classification: Protected A

Author	Year	Title	Ranking(1)
Hong, Lijing; Zhao, Qingliang; Jiang, Junqiu		Effect of the species distribution of heavy metals and heat supply.	
Yuan T. H.; Pien W. H.; Chan C. C.	2013	Urinary heavy metal levels of residents in the vicinity of a petrochemical complex in Taiwan	Strong
Liu, Jianwei; Chen, Yanjiao; Chao, Sihong; Cao, Hongbin; Zhang, Aichen; Yang, Yue	2018	Emission control priority of $PM_{2.5}$-bound heavy metals in different seasons: A comprehensive analysis from health risk perspective	Strong

Notes:
Ranking is based on degree to which information in an article meets specific criteria. Ranking Checklists are presented in APPENDIX C. Total possible score = 28 - (number of "n/a" * 2), where n/a means non-applicable criteria
Studies were considered to be weak (i.e., of low quality) if the total calculated score was ≤50%, moderate-weak if the total calculated score was 51-65%, moderate-strong if the total calculated score was 65-79% and strong (i.e., of high quality) if the total calculated score was ≥80%.
Links to the articles are provided in APPENDIX E.

Human Health Effects

The literature review identified four human health effects studies specifically evaluating emissions of manganese associated with electricity generation. Of the selected studies, all four were of high quality.

- Inhalation risks from metals (lead, zinc, arsenic, chromium, copper, manganese, nickel) in Changzhou, China from vehicular emissions, coal combustion and industrial sources were evaluated in a health assessment. The study found that carcinogenic risks from manganese for a 70-year exposure duration were slightly above target levels (i.e., incremental lifetime cancer risk >$1x10^{-6}$) (Bi et al. 2020). Risks were calculated for children and adults, with results provided for males and females. Manganese was found to be mainly sourced from vehicular emissions and industrial emissions (Bi et al. 2020). As a result, predicted risks may not be primarily from power plants/energy generation emissions.
- A risk assessment conducted in Harbin, China calculated average daily doses for children and adults of trace metals bound to PM, considering exposure from ingestion, inhalation, and dermal contact. The assessment concluded that manganese was a significant driver of exposure from all pathways evaluated (Wang et al. 2020). Ingestion was the most significant exposure pathway in the study, followed by dermal contact with inhalation exposure determined to be the least significant. Children were found mainly exposed to PM-bound metals via ingestion and dermal contact and adults were concluded to be mainlu exposed via inhalation. It is noted that emissions in the risk assessment were sourced from both vehicles and power plants.
- Increased urinary manganese levels were found to be correlated with increased age and proximity to apetrochemical complex (naptha cracking, oil refineries, coal-fired power plant), and higher in females, in a biological monitoring study of adult residents living in close proximity to a petrochemical complex in Yunlin County, Taiwan (Yuan et al. 2013). The study evaluated 10 metals (vanadium, manganese, strontium, arsenic, lead, copper, cadmium, nickel, chromium, thallium) to identify trends between age, gender and behaviour (i.e., smoking) and urinary levels of the 10 metals, and to determine appropriate biomarkers for assessments of similar petrochemical complexes.
- Manganese was determined to be one of the most significant drivers of non-carcinogenic risk in a risk assessment carried out in Beijing, China for atmospheric PM_{10}-bound metals (arsenic, barium, cadmium, cobalt, chromium (VI), manganese, nickel, vanadium). Sources of PM-bound metal emissions in the study area were determined to be (in decreasing order of magnitude) chromium-related industry, vehicular emissions, resuspended dust, copper-related industry and fuel oil and coal combustion (Liu et al. 2018). The study evaluated non-carcinogenic and carcinogenic risks from inhalation of PM-bound metals in ambient air.

Non-carcinogenic risks were calculated to be acceptable for all metals evaluated individually, and for total metals (i.e., hazard quotients <1). The total metal risk, however, was noted to be near the target risk level (i.e., hazard quotient calculated to be 0.89 compared to target hazard quotient of 1) (Liu et al. 2018). It is noted that risks were calculated based on metal concentrations from multiple sources, and power plants/energy generation was not the most significant source of emissions.

Ecological Effects

Biotic & Abiotic

No new literature was identified related to ecological health effects.

4.4.7 Chromium (Cr III and VI)

Table 15: Key Chromium Studies for Human Health Effects

Author	Year	Title	Ranking(1)
White Literature			
Xue, Qianqian; Jiang, Zhuo; Wang, Xiang; Song, Danlin; Huang, Fengxia; Tian, Yingze; Huang-fu, Yanqi; Feng, Yinchang	2019	Comparative study of PM_{10}-bound heavy metals and PAHs during six years in a Chinese megacity: Compositions, sources, and source-specific risks	Moderate-Strong
Bi, Chenglu; Chen, Yantong; Zhao, Zhuzi; Li, Qing; Zhou, Quanfa; Ye, Zhaolian; Ge, Xinlei	2020	Characteristics, sources and health risks of toxic species (PCDD/Fs, PAHs and heavy metals) in $PM_{2.5}$ during fall and winter in an industrial area	Strong
Wang, Kun; Wang, Weiye; Li, Lili; Li, Jianju; Wei, Liangliang; Chi, Wanqiu; Hong, Lijing; Zhao, Qingliang; Jiang, Junqiu	2020	Seasonal concentration distribution of PM_{10} and $PM_{2.5}$ and a risk assessment of bound trace metals in Harbin, China: Effect of the species distribution of heavy metals and heat supply.	Strong
Yuan T. H.; Pien W. H.; Chan C. C.	2013	Urinary heavy metal levels of residents in the vicinity of a petrochemical complex in Taiwan	Strong
Cai, Kui; Li, Chang; Na, Sanggyun	2019	Spatial distribution, pollution source, and health risk assessment of heavy metals in atmospheric depositions: A case study from the sustainable city of Shijiazhuang, China	Moderate-Strong
Liu, Jianwei; Chen, Yanjiao; Chao, Sihong; Cao, Hongbin; Zhang, Aichen; Yang, Yue	2018	Emission control priority of $PM_{2.5}$-bound heavy metals in different seasons: A comprehensive analysis from health risk perspective	Strong

Notes:
Ranking is based on degree to which information in an article meets specific criteria. Ranking Checklists are presented in APPENDIX C. Total possible score = 28 - (number of "n/a" * 2), where n/a means non-applicable criteria
Studies were considered to be weak (i.e., of low quality) if the total calculated score was ≤50%, moderate-weak if the total calculated score was 51-65%, moderate-strong if the total calculated score was 65-79% and strong (i.e., of high quality) if the total calculated score was ≥80%.
Links to the articles are provided in APPENDIX E.

Classification: Protected A

Human Health Effects

The literature review identified six human health effects study specifically evaluating emissions of chromium associated with electricity generation. Of the selected studies, four were of high quality and two were of moderate-strong quality.

- Non-carcinogenic risks (i.e., hazard quotients) were within acceptable levels (i.e., hazard quotients <1) for chromium and for all metals evaluated (arsenic, cadmium, lead, chromium, copper, nickel) in a risk assessment completed in Chengdu, China for atmospheric PM_{10}-bound metals. Carcinogenic risks (i.e., incremental lifetime cancer risks) for chromium (VI) and risks from the sum of all metals evaluated were associated with risks above the target level ($1x10^{-5}$ for chromium and for total metals versus target of $1x10^{-6}$) (Xue et al. 2019). Industrial sources of metals were considered to be high contributors of overall risk (Xue et al. 2019). Other sources of metal emissions in the study area included gasoline, diesel and coal combustion. It is noted that risks were calculated based on metal concentrations from multiple sources other than power plants/energy generation.
- Carcinogenic risks from chromium for a 70-year exposure duration were determined to be within acceptable levels (i.e., incremental lifetime cancer risk <$1x10^{-6}$) in a health assessment completed in an industrial area of Changzhou, a major city in China, which evaluated inhalation risks from metals (lead, zinc, arsenic, chromium, copper, manganese, nickel) from multiple sources including vehicular emissions, coal combustion and industrial sources (Bi et al. 2020). Risks were calculated for children and adults, with results provided for both males and females. Chromium was determined to be mainly sourced from crustal dust rather than energy generation/power plants (Bi et al. 2020).
- A risk assessment conducted in Harbin, China calculated average daily doses for children and adults of trace metals bound to PM, considering exposure from ingestion, inhalation, and dermal contact. The assessment concluded that chromium was a moderate was driver of exposure from all exposure pathways (Wang et al. 2020). The significance of the various exposure pathways, in decreasing order of magnitude, were determined to be ingestion, followed by dermal contact and then inhalation. Children were found to more exposed via ingestion and dermal contact than adults, while adults were concluded to be more exposed from inhalation. It is noted that emissions in the risk assessment were sourced from both vehicles and power plants.
- Adult residents living close to a petrochemical complex (naptha cracking, oil refineries, coal-fired power plant) were investigated through a biological monitoring study to determine the effects of exposure to 10 metals (vanadium, manganese, strontium, arsenic, lead, copper, cadmium, nickel, chromium, thallium) in Yunlin County, Taiwan. The study identified trends between age, gender and behaviour (i.e., smoking) and urinary levels of the 10 metals, and determined appropriate biomarkers for assessments of similar petrochemical complexes. Increased urinary chromium levels were found to be correlated with increased age and higher in females than in males (Yuan et al. 2013).
- Atmospheric emissions in Shijiazhuang, China were evaluated to determine sources, distribution, and health effects from deposition of metals (i.e., cadmium, chromium, copper, lead, nickel and zinc). The study determined that chromium was associated with natural sources (Cai et al. 2019). The health risk assessment determined that non-carcinogenic and carcinogenic risks for both children and adults were determined to be within the acceptable risk threshold (i.e., hazard quotients <1, incremental lifetime cancer risks <$1x10^{-6}$) for incidental ingestion, dermal contact and inhalation for all metals evaluated (Cai et al. 2019).

Classification: Protected A

- A risk assessment completed for Beijing, China considered atmospheric PM_{10}-bound metals (arsenic, barium, cadmium, cobalt, chromium (VI), manganese, nickel, vanadium) to evaluate non-carcinogenic and carcinogenic inhalation risks from ambient air. Non-carcinogenic risks were calculated to be acceptable for all metals evaluated individually (i.e., hazard quotients <1), and for total metals although the total metal risk was noted to be near the target risk level (i.e., hazard quotient calculated to be 0.89 compared to target hazard quotient of 1) (Liu et al. 2018). Carcinogenic risks for chromium (VI) met target risk levels (i.e., carcinogenic risk equal to $1x10^{-6}$) however carcinogenic risk for total metals was above the acceptable risk level (i.e., incremental lifetime cancer risks $>1x10^{-6}$) (Liu et al. 2018). Chromium-related industry, vehicular emissions, resuspended dust, copper-related industry and fuel oil and coal combustion were determined to be the source of metal emissions in the study area, listed in decreasing order of magnitude (Liu et al. 2018). Therefore, it is noted that risks were calculated based on metal concentrations from multiple sources, and power plants/energy generation was not the most significant source of emissions.

Ecological Effects

Biotic & Abiotic

No new literature was identified related to ecological health effects.

4.5 Category 3 Substances

4.5.1 Copper (Cu)

Table 16: Key Copper Studies for Human Health Effects

Author	Year	Title	Ranking(1)
White LIterature			
Bi, Chenglu; Chen, Yantong; Zhao, Zhuzi; Li, Qing; Zhou, Quanfa; Ye, Zhaolian; Ge, Xinlei	2020	Characteristics, sources and health risks of toxic species (PCDD/Fs, PAHs and heavy metals) in $PM_{2.5}$ during fall and winter in an industrial area	Strong
Wang, Kun; Wang, Weiye; Li, Lili; Li, Jianju; Wei, Liangliang; Chi, Wanqiu; Hong, Lijing; Zhao, Qingliang; Jiang, Junqiu	2020	Seasonal concentration distribution of PM_{10} and $PM_{2.5}$ and a risk assessment of bound trace metals in Harbin, China: Effect of the species distribution of heavy metals and heat supply.	Strong
Yuan T. H.; Pien W. H.; Chan C. C.	2013	Urinary heavy metal levels of residents in the vicinity of a petrochemical complex in Taiwan	Strong
Cai, Kui; Li, Chang; Na, Sanggyun	2019	Spatial distributio, pollution source, and health Risk assessment of heavy metals in atmospheric depositions: A case study from the sustainable city of Shijiazhuang, China	Moderate-Strong
Chen, Chi-Hsin Sally; Yuan, Tzu-Hsuen; Shie, Ruei-Hao; Wu, Kuen-Yuh; Chan, Chang-Chuan	2017	Linking sources to early effects by profiling urine metabolome of residents living near oil refineries and coal-fired power plants	Strong

Notes:
Ranking is based on degree to which information in an article meets specific criteria. Ranking Checklists are presented in APPENDIX C. Total possible score = 28 - (number of "n/a" * 2), where n/a means non-applicable criteria
Studies were considered to be weak (i.e., of low quality) if the total calculated score was ≤50%, moderate-weak if the total calculated score was 51-65%, moderate-strong if the total calculated score was 65-79% and strong (i.e., of high quality) if the total calculated score was ≥80%.
Links to the articles are provided in APPENDIX E.

Classification: Protected A

Human Health Effects

The literature review identified five human health effects studies specifically evaluating emissions of copper associated with electricity generation. Of the selected studies, four were of high quality and one was of moderate-strong quality.

- Copper was found to be mainly sourced from vehicular emissions in a health assessment completed in an industrial area of Changzhou, China (Bi et al. 2020). The assessment evaluated inhalation risks from metals (lead, zinc, chromium, arsenic, copper, manganese, nickel) from multiple sources including vehicular emissions, coal combustion and industrial sources. The study found that carcinogenic risks from copper over a lifetime (70 years) were within acceptable levels (i.e., incremental lifetime cancer risk $<1x10^{-6}$) (Bi et al. 2020). Risks were calculated for both children and adults, with results separated for males and females.
- A risk assessment conducted in Harbin, China calculated average daily doses for children and adults of trace PM-bound metals for ingestion, inhalation, and dermal contact exposure. Ingestion was determined to be the most significant exposure pathway, followed by dermal contact and inhalation. Ingestion and dermal contact exposure pathways were most relevant for children and inhalation exposure was most relevant for adults. The assessment concluded that copper posed a was a significant driver of exposure from all exposure pathways (Wang et al. 2020). However, it is noted that emissions in the risk assessment were sourced from both vehicles and power plants.
- A biological monitoring study in Yunlin County, Taiwan evaluated adult residents living close to a petrochemical complex (naptha cracking, oil refineries, coal-fired power plant). The study investigated the effects of 10 metals (vanadium, manganese, strontium, arsenic, lead, copper, cadmium, nickel, chromium, thallium) to establish trends between age, gender and behaviour (i.e., smoking) and urinary levels of the 10 metals, and to determine appropriate biomarkers for assessments of similar petrochemical complexes. Increased urinary copper levels were found to be correlated with increased age and in females, and unlike most metals in the study copper urinary concentrations were higher in those living further from the petrochemical complex than those closer to it (Yuan et al. 2013).
- A health risk assessment of atmospheric emissions in Shijiazhuang, China for metals (i.e., cadmium, chromium, copper, lead, nickel, and zinc) determined that copper was associated with traffic emissions (Cai et al. 2019). The health risk assessment determined that non-carcinogenic and carcinogenic risks for both children and adults were determined to be within the acceptable risk threshold (i.e., hazard quotients <1, incremental lifetime cancer risks $<1x10^{-6}$) for incidental ingestion, dermal contact and inhalation for all metals evaluated (Cai et al. 2019).
- A study in Yunlin County, Taiwan compared estimated emission exposure concentrations of metals (vanadium, nickel, copper, arsenic, strontium, cadmium, mercury, thallium) from coal-fired power plants to urine concentrations of in 252 test subjects (children aged 9-15 years and elderly aged >55 years) (Chen et al. 2017). Both “low” exposure (further distance from homes to power plant; 141 individuals) and a “high” exposure (closer distance from home to power plant; 111 individuals) individuals were evaluated. The study found that “high” exposure subjects had increase urine concentrations of copper, , along with higher concentrations of urine oxidative stress biomarkers associated with chronic diseases and allergic respiratory diseases, compared to the “low” exposure subjects (Chen et al. 2017).

Classification: Protected A

Ecological Effects

Biotic & Abiotic

No new literature was identified related to ecological health effects.

4.5.2 Strontium (Sr)

Table 17: Key Strontium Studies for Human Health Effects

Author	Year	Title	Ranking(1)
White Literature			
Yuan T. H.; Pien W. H.; Chan C. C.	2013	Urinary heavy metal levels of residents in the vicinity of a petrochemical complex in Taiwan	Strong
Chen, Chi-Hsin Sally; Yuan, Tzu-Hsuen; Shie, Ruei-Hao; Wu, Kuen-Yuh; Chan, Chang-Chuan	2017	Linking sources to early effects by profiling urine metabolome of residents living near oil refineries and coal-fired power plants	Strong

Notes:
Ranking is based on degree to which information in an article meets specific criteria. Ranking Checklists are presented in APPENDIX C. Total possible score = 28 - (number of "n/a" * 2), where n/a means non-applicable criteria
Studies were considered to be weak (i.e., of low quality) if the total calculated score was ≤50%, moderate-weak if the total calculated score was 51-65%, moderate-strong if the total calculated score was 65-79% and strong (i.e., of high quality) if the total calculated score was ≥80%.
Links to the articles are provided in APPENDIX E.

Human Health Effects

The literature review identified two human health effects study specifically evaluating emissions of strontium associated with electricity generation. The identified studies were of high quality.

- Biological monitoring study identified trends between age, gender, and behaviour (i.e., smoking) and urinary levels of 10 metals (vanadium, manganese, strontium, arsenic, lead, copper, cadmium, nickel, chromium, thallium) in adults in Yunlin Taiwan living close to a petrochemical complex. The study also determined strontium as an appropriate biomarker for assessments of similar petrochemical complexes (naptha cracking, oil refineries, coal-fired power plant). Increased urinary strontium levels were found to be correlated with proximity to the petrochemical complex and higher in females than in males (Yuan et al. 2013).
- Urine concentrations of metals (vanadium, nickel, copper, arsenic, strontium, cadmium, mercury, thallium) in 252 test subjects (children aged 9-15 years and elderly aged >55 years) living near coal-fired power plants in Yunlin County, Taiwan were evaluated (Chen et al. 2017). Subjects were classified as “low” exposure (further distance from homes to power plant; 141 individuals) or “high” exposure (closer distance from home to power plant; 111 individuals). The study found that “high” exposure subjects had increase urine concentrations of strontium, along with higher concentrations of urine biomarkers related to chronic diseases and allergic respiratory diseases, compared to the “low” exposure subjects (Chen et al. 2017).

Ecological Effects

Biotic & Abiotic

No new literature was identified related to ecological health effects.

Classification: Protected A

4.5.3 Thallium (Tl)

Table 18: Key Thallium Studies for Human Health Effects

Author	Year	Title	Ranking(1)
White Literature			
Yuan T. H.; Pien W. H.; Chan C. C.	2013	Urinary heavy metal levels of residents in the vicinity of a petrochemical complex in Taiwan	Strong
Chen, Chi-Hsin Sally; Yuan, Tzu-Hsuen; Shie, Ruei-Hao; Wu, Kuen-Yuh; Chan, Chang-Chuan	2017	Linking sources to early effects by profiling urine metabolome of residents living near oil refineries and coal-fired power plants	Strong

Notes:
Ranking is based on degree to which information in an article meets specific criteria. Ranking Checklists are presented in APPENDIX C. Total possible score = 28 - (number of "n/a" * 2), where n/a means non-applicable criteria
Studies were considered to be weak (i.e., of low quality) if the total calculated score was ≤50%, moderate-weak if the total calculated score was 51-65%, moderate-strong if the total calculated score was 65-79% and strong (i.e., of high quality) if the total calculated score was ≥80%.
Links to the articles are provided in APPENDIX E.

Human Health Effects

The literature review identified two human health effects study specifically evaluating emissions of thallium associated with electricity generation. Both of the identified studies were of high quality.

- Increased urinary thallium levels were found to be higher in females than in males in adult residents living close to a petrochemical complex (naptha cracking, oil refineries, coal-fired power plant) in Yunlin County, Taiwan (Yuan et al. 2013). This was determined in a biological monitoring study which identified trends between age, gender, and behaviour (i.e., smoking) and urinary levels of 10 metals (vanadium, manganese, strontium, arsenic, lead, copper, cadmium, nickel, chromium, thallium), and determined appropriate biomarkers for assessments of similar petrochemical complexes.
- 252 test subjects (children aged 9-15 years and elderly aged >55 years) living near coal-fired power plants in Yunlin County, Taiwan were classified as "low" exposure (further distance from homes to power plant; 141 individuals) or "high" exposure (closer distance from home to power plant; 111 individuals) (Chen et al. 2017). The study compared estimated metal (vanadium, nickel, copper, arsenic, strontium, cadmium, mercury, thallium) emission exposure concentrations to urine concentrations of these substances in the test subjects. The study found that "high" exposure subjects had increase urine concentrations of thallium, along with higher concentrations of urine oxidative stress biomarkers associated with chronic diseases and allergic respiratory diseases, compared to the "low" exposure subjects (Chen et al. 2017).

Ecological Effects

Biotic & Abiotic

No new literature was identified related to ecological health effects.

Classification: Protected A

4.5.4 Zinc (Zn)

Table 19: Key Zinc Studies for Human Health Effects

Author	Year	Title	Ranking(1)
White LIterature			
Bi, Chenglu; Chen, Yantong; Zhao, Zhuzi; Li, Qing; Zhou, Quanfa; Ye, Zhaolian; Ge, Xinlei	2020	Characteristics, sources and health risks of toxic species (PCDD/Fs, PAHs and heavy metals) in $PM_{2.5}$ during fall and winter in an industrial area	Strong
Wang, Kun; Wang, Weiye; Li, Lili; Li, Jianju; Wei, Liangliang; Chi, Wanqiu; Hong, Lijing; Zhao, Qingliang; Jiang, Junqiu	2020	Seasonal concentration distribution of PM_{10} and $PM_{2.5}$ and a risk assessment of bound trace metals in Harbin, China: Effect of the species distribution of heavy metals and heat supply.	Strong
Cai, Kui; Li, Chang; Na, Sanggyun	2019	Spatial distribution, pollution source, and health Risk assessment of heavy metals in atmospheric depositions: A case study from the sustainable city of Shijiazhuang, China	Moderate-Strong

Notes:
Ranking is based on degree to which information in an article meets specific criteria. Ranking Checklists are presented in APPENDIX C. Total possible score = 28 - (number of "n/a" * 2), where n/a means non-applicable criteria
Studies were considered to be weak (i.e., of low quality) if the total calculated score was ≤50%, moderate-weak if the total calculated score was 51-65%, moderate-strong if the total calculated score was 65-79% and strong (i.e., of high quality) if the total calculated score was ≥80%.
Links to the articles are provided in APPENDIX E.

Human Health Effects

The literature review identified three human health effects studies specifically evaluating emissions of zinc associated with electricity generation. Of the identified studies, two were of high quality and one was of moderate-strong quality.

- A health assessment completed in an industrial area of Changzhou, a major city in China, found that carcinogenic risks from zinc for a 70-year exposure duration were within acceptable levels (i.e., incremental lifetime cancer risk <$1x10^{-6}$) (Bi et al. 2020). The assessment evaluated metals (lead, zinc, chromium, arsenic, copper, manganese, nickel) from multiple sources including vehicular emissions, coal combustion and industrial sources. Risks were calculated for both children and adults, with results separated for males and females. Zinc was found to be mainly sourced from vehicular emissions (Bi et al. 2020).
- A risk assessment conducted in Harbin, China calculated average daily doses for children and adults of trace metals bound to PM, considering exposure from ingestion, inhalation, and dermal contact. The assessment concluded that zinc was a significant driver of exposure from all exposure pathways, and was the most significant driver of risk of all other metals considered (chromium, nickel, cadmium, cobalt, lead, copper, manganese) (Wang et al. 2020). Ingestion was the most significant exposure pathway in the study, followed by dermal contact and then inhalation. Children were mainly exposed via ingestion and dermal contact and adults were mainly exposed from inhalation exposure. It is noted that emissions in the risk assessment were sourced from both vehicles and power plants.
- A health risk assessment determined that non-carcinogenic and carcinogenic risks for both children and adults were determined to be within the acceptable risk threshold (i.e., hazard quotients <1, incremental lifetime cancer risks <$1x10^{-6}$) for incidental ingestion, dermal contact and inhalation for zinc, and for all metals evaluated in the study (i.e., cadmium, chromium, copper, lead, nickel) (Cai et al. 2019). The study was carried out in Shijiazhuang, China. Atmospheric emissions of zinc which deposited to soil were found to be attributable to coal-fired power plants.

Classification: Protected A

Ecological Effects

Biotic & Abiotic

No new literature was identified related to ecological health effects.

4.5.5 Nickel (Ni)

Table 20: Key Nickel Studies for Human Health Effects

Author	Year	Title	Ranking(1)
White Literature			
Xue, Qianqian; Jiang, Zhuo; Wang, Xiang; Song, Danlin; Huang, Fengxia; Tian, Yingze; Huang-fu, Yanqi; Feng, Yinchang	2019	Comparative study of PM_{10}-bound heavy metals and PAHs during six years in a Chinese megacity: Compositions, sources, and source-specific risks	Moderate-Strong
Bi, Chenglu; Chen, Yantong; Zhao, Zhuzi; Li, Qing; Zhou, Quanfa; Ye, Zhaolian; Ge, Xinlei	2020	Characteristics, sources and health risks of toxic species (PCDD/Fs, PAHs and heavy metals) in $PM_{2.5}$ during fall and winter in an industrial area	Strong
Wang, Kun; Wang, Weiye; Li, Lili; Li, Jianju; Wei, Liangliang; Chi, Wanqiu; Hong, Lijing; Zhao, Qingliang; Jiang, Junqiu	2020	Seasonal concentration distribution of PM_{10} and $PM_{2.5}$ and a risk assessment of bound trace metals in Harbin, China: Effect of the species distribution of heavy metals and heat supply.	Strong
Yuan T. H.; Pien W. H.; Chan C. C.	2013	Urinary heavy metal levels of residents in the vicinity of a petrochemical complex in Taiwan	Strong
Cai, Kui; Li, Chang; Na, Sanggyun	2019	Spatial distribution, pollution source, and health Risk assessment of heavy metals in atmospheric depositions: A case study from the sustainable city of Shijiazhuang, China	Moderate-Strong
Chen, Chi-Hsin Sally; Yuan, Tzu-Hsuen; Shie, Ruei-Hao; Wu, Kuen-Yuh; Chan, Chang-Chuan	2017	Linking sources to early effects by profiling urine metabolome of residents living near oil refineries and coal-fired power plants	Strong
Liu, Jianwei; Chen, Yanjiao; Chao, Sihong; Cao, Hongbin; Zhang, Aichen; Yang, Yue	2018	Emission control priority of $PM_{2.5}$-bound heavy metals in different seasons: A comprehensive analysis from health risk perspective	Strong

Notes:
Ranking is based on degree to which information in an article meets specific criteria. Ranking Checklists are presented in APPENDIX C. Total possible score = 28 - (number of "n/a" * 2), where n/a means non-applicable criteria
Studies were considered to be weak (i.e., of low quality) if the total calculated score was ≤50%, moderate-weak if the total calculated score was 51-65%, moderate-strong if the total calculated score was 65-79% and strong (i.e., of high quality) if the total calculated score was ≥80%.
Links to the articles are provided in APPENDIX E.

Human Health Effects

The literature review identified seven human health effects studies specifically evaluating emissions of nickel associated with electricity generation. Of the identified studies, five were of high quality and two were of moderate-strong quality.

- Atmospheric PM_{10}-bound metals (arsenic, cadmium, lead, chromium, copper, nickel) from multiple sources including gasoline, diesel and coal combustion and industrial sources were evaluated in a risk assessment completed in Chengdu, China. Non-carcinogenic risks (i.e., hazard quotients) were found to be within acceptable levels for all metals evaluated (i.e., hazard quotients <1). Carcinogenic risks (i.e., incremental lifetime cancer risks) for nickel and risks from the sum of all metals evaluated were associated with risks above the target level ($6x10^{-6}$ to $1x10^{-5}$ for nickel and $1x10^{-5}$ for total metals versus target of $1x10^{-6}$) (Xue et al. 2019). Industrial sources of metals were considered to be high contributors to overall risk (Xue et al. 2019). It is noted that risks were calculated based on metal concentrations from multiple sources other than power plants/energy generation.
- A health assessment completed in an industrial area of Changzhou, a major city in China, evaluated inhalation risks from metals (lead, zinc, chromium, arsenic, copper, manganese, nickel) for children and adults, with results provided for both males and females, and nickel posed a risk to both adults and children. The study found that carcinogenic risks from nickel for a 70-year exposure duration were above acceptable levels ($1x10^{-4}$ for nickel versus target level of $1x10^{-6}$) (Bi et al. 2020). Metal emission sources in the study area included vehicular emissions, coal combustion and industrial sources. Nickel was found to be mainly from industrial emissions and coal combustion however it is noted that the concentrations used to estimate risk were sourced from multiple emission sources (Bi et al. 2020).
- A risk assessment conducted in Harbin, China calculated average daily doses for children and adults of trace metals bound to PM, considering exposure from ingestion (most significant exposure pathway), inhalation (least significant exposure pathway), and dermal contact. Children were found to more exposed than adults via ingestion and dermal contact with PM, while adults were concluded to be more exposed than children from inhalation. The assessment concluded that nickel was a significant driver of exposure from all exposure pathways (Wang et al. 2020). It is noted that emissions in the risk assessment were sourced from both vehicles and power plants.
- Increased urinary nickel levels were found to be correlated with increased age and higher in females through a biological monitoring study of adult residents living close to a petrochemical complex (naptha cracking, oil refineries, coal-fired power plant) in Yunlin County, Taiwan (Yuan et al. 2013). The study identified trends between age, gender and behaviour (i.e., smoking) and urinary levels of 10 metals (vanadium, manganese, strontium, arsenic, lead, copper, cadmium, nickel, chromium, thallium), and determined appropriate biomarkers for assessments of similar petrochemical complexes.
- A study of sources, distribution, and health effects from deposition of metals (i.e., cadmium, chromium, copper, lead, nickel, and zinc) from atmospheric emissions in Shijiazhuang, a Chinese city, determined that nickel was associated with natural sources (Cai et al. 2019). The health risk assessment determined that non-carcinogenic and carcinogenic risks for both children and adults were determined to be below the acceptable risk threshold (i.e., hazard quotients <1, incremental lifetime cancer risks $<1x10^{-6}$) for incidental ingestion, dermal contact and inhalation for the metals evaluated (Cai et al. 2019).
- A study in Yunlin County, Taiwan compared estimated emission exposure concentrations metals (vanadium, nickel, copper, arsenic, strontium, cadmium, mercury, thallium) to urine concentrations of these substances in 252 test subjects (children aged 9-15 years and elderly aged >55 years) living near coal-fired power plants (Chen et al. 2017). The study found that “high” exposure subjects (closer distance from home to power plant; 111 individuals) had increased urine concentrations of nickel, , along with higher concentrations of urine oxidative stress biomarkers associated with chronic diseases and allergic respiratory diseases, compared to the “low” exposure subjects (further distance from homes to power plant; 141 individuals) (Chen et al. 2017).

Classification: Protected A

- A risk assessment completed for Beijing, China considered atmospheric PM_{10}-bound metals (arsenic, barium, cadmium, cobalt, chromium (VI), manganese, nickel, vanadium) to evaluate non-carcinogenic and carcinogenic risks from inhalation of ambient air. Non-carcinogenic risks were calculated to be acceptable for all metals evaluated individually (i.e., hazard quotients <1), and for total metals although the total metal risk was noted to be near the target risk level (i.e., hazard quotient calculated to be 0.89 compared to target hazard quotient of 1) (Liu et al. 2018). Carcinogenic risks for nickel were below the acceptable level (i.e., cancer risk $<1x10^{-6}$) (Liu et al. 2018). Sources of PM-bound metal emissions were determined to be (in decreasing order) chromium-related industry, vehicular emissions, re-suspended dust, copper-related industry and fuel oil and coal combustion (Liu et al. 2018). Therefore, it is noted that risks were calculated based on metal concentrations from multiple sources, and power plants/energy generation was not the most significant source of emissions.

Ecological Effects

Biotic & Abiotic

No new literature was identified related to ecological health effects.

4.5.6 Vanadium (V)

Table 21: Key Vanadium Studies for Human Health Effects

Author	Year	Title	Ranking(1)
White Literature			
Yuan T. H.; Pien W. H.; Chan C. C.	2013	Urinary heavy metal levels of residents in the vicinity of a petrochemical complex in Taiwan	Strong
Chen, Chi-Hsin Sally; Yuan, Tzu-Hsuen; Shie, Ruei-Hao; Wu, Kuen-Yuh; Chan, Chang-Chuan	2017	Linking sources to early effects by profiling urine metabolome of residents living near oil refineries and coal-fired power plants	Strong

Notes:
Ranking is based on degree to which information in an article meets specific criteria. Ranking Checklists are presented in APPENDIX C. Total possible score = 28 - (number of "n/a" * 2), where n/a means non-applicable criteria
Studies were considered to be weak (i.e., of low quality) if the total calculated score was ≤50%, moderate-weak if the total calculated score was 51-65%, moderate-strong if the total calculated score was 65-79% and strong (i.e., of high quality) if the total calculated score was ≥80%.
Links to the articles are provided in APPENDIX E.

Human Health Effects

The literature review identified two human health effects studies specifically evaluating emissions of vanadium associated with electricity generation. Of the identified studies, both were of high quality.

- A biological monitoring study in Taiwan (Yunlin County) of adult residents living close to a petrochemical complex (naptha cracking, oil refineries, coal-fired power plant) investigated the effects of 10 metals (vanadium, manganese, strontium, arsenic, lead, copper, cadmium, nickel, chromium, thallium). The study identified trends between age, gender and behaviour (i.e., smoking) and urinary levels of the 10 metals, and determined that vanadium as an appropriate biomarker for assessments of similar petrochemical complexes. Increased urinary vanadium levels were found to be higher in females and correlated with proximity to the petrochemical complex (Yuan et al. 2013).

- Metal (vanadium, nickel, copper, arsenic, strontium, cadmium, mercury, thallium) emission exposure concentrations were compared to urine concentrations of these substances in 252 test subjects (children aged 9-15 years and elderly aged >55 years) living near coal-fired power plants in Yunlin County, Taiwan (Chen et al. 2017). Both "low" exposure (further distance from homes to power plant; 141 individuals) and a "high" exposure (closer distance from home to power plant; 111 individuals) individuals were evaluated. The study found that "high" exposure subjects had increase urine concentrations of vanadium, along with higher concentrations of urine oxidative stress biomarkers indicative of chronic diseases and allergic respiratory diseases, compared to the "low" exposure subjects (Chen et al. 2017).

Ecological Effects

Biotic & Abiotic

No new literature was identified related to ecological health effects.

4.5.7 Polycyclic Aromatic Hydrocarbons (PAHs)

Table 22: Key Polycyclic Aromatic Hydrocarbon Studies for Human Health Effects

Author	Year	Title	Ranking(1)
White Literature			
Xue, Qianqian; Jiang, Zhuo; Wang, Xiang; Song, Danlin; Huang, Fengxia; Tian, Yingze; Huang-fu, Yanqi; Feng, Yinchang	2019	Comparative study of PM_{10}-bound heavy metals and PAHs during six years in a Chinese megacity: Compositions, sources, and source-specific risks	Strong
Bi, Chenglu; Chen, Yantong; Zhao, Zhuzi; Li, Qing; Zhou, Quanfa; Ye, Zhaolian; Ge, Xinlei	2020	Characteristics, sources and health risks of toxic species (PCDD/Fs, PAHs and heavy metals) in $PM_{2.5}$ during fall and winter in an industrial area	Strong
Wang, Ruwei; Liu, Guijian; Zhang, Jiamei	2015	Variations of emission characterization of PAHs emitted from different utility boilers of coal-fired power plants and risk assessment related to atmospheric PAHs.	Moderate-Strong
Tian, Kai; Bao, Huanyu; Zhang, Xuechen; Shi, Taoran; Liu, Xueping; Wu, Fuyong	2018	Residuals, bioaccessibility and health risk assessment of PAHs in winter wheat grains from areas influenced by coal combustion in China.	Strong
Guo L; Hu J; Xing Y; Wang H; Miao S; Meng Q; Wang X; Bai S; Jia J; Wang P; Zhang R; Gao P	2020	Sources, environmental levels, and health risks of $PM_{2.5}$-bound polycyclic aromatic hydrocarbons in energy-producing cities in northern China.	Moderate-Strong
Sarkar S; Khillare PS	2013	Profile of PAHs in the inhalable particulate fraction: source apportionment and associated health risks in a tropical megacity.	Weak
Gune, Minal Milind; Ma, Wan-Li; Sampath, Srimurali; Li, Wenlong; Li, Yi-Fan; Udayashankar, Harikripa Narayana; Balakrishna, Keshava	2019	Occurrence of polycyclic aromatic hydrocarbons (PAHs) in air and soil surrounding a coal-fired thermal power plant in the south-west coast of India	Moderate-Strong

Author	Year	Title	Ranking[1]
Qun Wang, Zhangsen Dong, Yue Guo, Fei Yu, Zhenya Zhang, Ruiqin Zhang	2020	Characterization of $PM_{2.5}$-bound polycyclic aromatic hydrocarbons at two central China cities: Seasonal variation, sources, and health risk assessment	Weak
Yan Zha, Yin L. Zhang, Jie Tang & Kai Sun	2018	Status, sources, and human health risk assessment of PAHs via foliar dust from different functional areas in Nanjing, China	Strong
Zhang L; Xu H; Fang B; Wang H; Yang Z; Yang W; Hao Y; Wang X; Wang Q; Wang M	2019	Source identification and health risk assessment of polycyclic aromatic hydrocarbon-enriched $PM_{2.5}$ in Tangshan, China	Strong
Popadić, Désirée; Heßelbach, Katharina; Richter-Brockmann, Sigrid; Kim, Gwang-Jin; Flemming, Stephan; Schmidt-Heck, Wolfgang; Häupl, Thomas; Bonin, Marc; Dornhof, Regina; Achten, Christine; Günther, Stefan; Humar, Matjaz; Merfort, Irmgard	2018	Gene expression profiling of human bronchial epithelial cells exposed to fine particulate matter ($PM_{2.5}$) from biomass combustion.	Moderate-Strong
Gao, Bo; Wang, Xin-Ming; Zhao, Xiu-Ying; Ding, Xiang; Fu, Xiao-Xin; Zhang, Yan-Li; He, Quan-Fu; Zhang, Zhou; Liu, Teng-Yu; Huang, Zou-Zhao; Chen, Lai-Guo; Peng, Yan; Guo, Hai	2015	Source apportionment of atmospheric PAHs and their toxicity using PMF: Impact of gas/particle partitioning.	Moderate-Strong
Chao S; Liu J; Chen Y; Cao H; Zhang A	2019	Implications of seasonal control of $PM_{2.5}$-bound PAHs: An integrated approach for source apportionment, source region identification and health risk assessment.	Strong
Wang, Xue-Tong; Miao, Yi; Zhang, Yuan; Li, Yuan-Cheng; Wu, Ming-Hong; Yu, Gang	2013	Polycyclic aromatic hydrocarbons (PAHs) in urban soils of the megacity Shanghai: Occurrence, source apportionment and potential human health risk	Moderate-Strong
Xu, Hongmei; Ho, Steven Sai Hang; Gao, Meiling; Cao, Junji; Guinot, Benjamin; Ho, Kin Fai; Long, Xin; Wang, Jingzhi; Shen, Zhenxing; Liu, Suixin; Zheng, Chunli; Zhang, Qian	2016	Microscale spatial distribution and health assessment of $PM_{2.5}$-bound polycyclic aromatic hydrocarbons (PAHs) at nine communities in Xi'an, China	Moderate-Strong
Yan, Daohao; Wu, Shaohua; Zhou, Shenglu; Tong, Guijie; Li, Fufu; Wang, Yuanmin; Li, Baojie	2019	Characteristics, sources and health risk assessment of airborne particulate PAHs in Chinese cities: A review	Strong

Notes:
Ranking is based on degree to which information in an article meets specific criteria. Ranking Checklists are presented in APPENDIX C. Total possible score = 28 - (number of "n/a" * 2), where n/a means non-applicable criteria
Studies were considered to be weak (i.e., of low quality) if the total calculated score was ≤50%, moderate-weak if the total calculated score was 51-65%, moderate-strong if the total calculated score was 65-79% and strong (i.e., of high quality) if the total calculated score was ≥80%.
Links to the articles are provided in APPENDIX E.

Classification: Protected A

Human Health Effects

The literature review identified 23 human health effects studies specifically evaluating emissions of PAHs associated with electricity generation. Following review of the full texts of each study, 16 studies were retained for evaluation and summarized below. Of the 16 selected studies, seven were of high quality, seven were of moderate-strong quality and two were of low quality. The seven studies which were not summarized below were evaluated via the Checklist in APPENDIX C.

- A risk assessment completed for Chengdu, a Chinese megacity, which considered atmospheric PM_{10}-bound PAHs, individually and cumulatively, from multiple sources including gasoline, diesel and coal combustion and industrial sources found that non-carcinogenic risks (i.e., hazard quotients) were within acceptable levels (i.e., hazard quotients <1). Carcinogenic risks (i.e., incremental lifetime cancer risks) were associated with risks above the target level (5.7×10^{-6} to 9.8×10^{-6} for total PAHs versus target risk level of 1×10^{-6}) (Xue et al. 2019). Other air pollutants including metals were considered by this study and were considered to be higher contributors to the overall risk than PAHs (Xue et al. 2019). It is noted that risks were calculated based on PAH concentrations from multiple sources other than power plants/energy generation.
- A health assessment completed in an industrial area of Changzhou, a major city in China, evaluated inhalation risks from PM-bound PAHs from multiple sources including vehicular emissions and coal combustion (largest contributors), and industrial sources. The study found carcinogenic risks associated above target levels (1×10^{-5} versus 1×10^{-6}) with PAHs (cumulative assessment of 18 PAHs) for a 70-year exposure duration (Bi et al. 2020).
- A risk assessment in China (multiple cities) evaluated risks to humans ingesting wheat grain grown in fields surrounding coal-fired power plants. PAH emissions from the power plants deposited on the wheat grain, and the study found increased risk of cancer (above 1×10^{-6} target risk level) in children (4-10 years), teens (11-17 years), adults (18-60 years) and seniors (61-70 years) from ingestion based on total PAH exposure (Tian et al. 2018). The risk assessment found that children were the most sensitive to PAH exposure via ingestion of wheat grains which had accumulated PAHs from coal-fired power plant emissions, and that males were more sensitive than females in the child, teen and adult age groups (Tian et al. 2018).
- A risk assessment in northern China (multiple cities) calculated incremental lifetime cancer risks to adults from exposure to PM-bound PAHs in outdoor air in emissions from coal-energy and oil-energy generating cities and found that incremental lifetime cancer risks were acceptable (relative to a target threshold of 1×10^{-5}) especially when the bioaccessibility of PAHs was considered (Guo et al. 2020). The study noted however, that incremental cancer risks may be underestimated as the study was limited to outdoor air and residents in the cities evaluated may spend significant time indoors where they may be exposed to additional sources of PAH (e.g., from biomass burning for heat).
- A risk assessment conducted for Delhi, a megacity in India, evaluated the inhalation health risks associated with cumulative (i.e., individual species concentrations summed) PAH (PM bound) exposure in ambient air in three residential areas sourced from vehicular emissions, coal combustion, residential fuel use and industrial emissions (Sarkar & Khillare 2013). The study found that inhalation exposure to PAHs over a lifetime (70 years) could result in up to approximately 40,000 additional cases of cancer in the population of Delhi, India. However, it is noted that emissions in the risk assessment were sourced from multiple sources, with vehicular emissions being the highest contributor (62-83%, followed by coal combustion 18-19%) (Sarkar & Khillare 2013).

Classification: Protected A

- A study of PAH emissions from a coal-fired thermal power plant in the south-west coast of India evaluated concentrations of PAHs in both ambient air and soil found that PAH concentrations were highest in soil, indicating exposure from contact with soil contaminated via deposition was a more significant health risk than inhalation exposure (Gune et al. 2019). A toxic equivalent quotient and mutagenic equivalent quotient was calculated for cumulative high molecular weight PAHs and indicated that soil concentrations of PAHs may be associated with increased cancer risks. However, it is noted that emissions in the assessment originated from both coal-fired thermal power plant emissions and vehicular exhaust (Gune et al. 2019).
- A risk assessment conducted for two industrial cities, Luoyang and Pingdingshan, in China evaluated the inhalation health risks associated with cumulative (i.e., individual species concentrations summed) PAH (PM bound) exposure in ambient air (Wang et al. 2020). The study found that inhalation exposure to PAHs over a lifetime (70 years) could resulted in an average lifetime inhalation cancer risk two orders of magnitude higher than the acceptable risk level ($1x10^{-4}$ risk identified versus $1x10^{-6}$ target level). It is noted that emissions in the risk assessment for both cities were sourced from multiple sources, with coal combustion being the highest contributor followed by vehicular emissions, however in one city vehicular emissions were determined to drive the cancer risk (Wang et al. 2020). It is noted that the coal combustion emissions were a result of both residential and industrial burning.
- A risk assessment was conducted for Nanjing, an industrial city in China, for cumulative (i.e., individual species concentrations summed) PAH exposure in foliar dust via inhalation, ingestion, and dermal contact for three age groups (2-10 years; 11-17 years; 18-70 years) divided by gender (Zha et al. 2018). The study found that exposure to PAHs in foliar dust increased the incremental lifetime cancer risk for all age/gender groups above the acceptable risk level (above $1x10^{-6}$ target level). The increased cancer risk was driven by dermal and ingestion exposure, with inhalation exposure considered to be nearly negligible. The PAH concentrations in dust in the study area were determined to be related to fuel (e.g., fossil fuel, coal, biomass) combustion and vehicular exhaust (Zha et al. 2018). It is noted that fuel combustion sources of PAHs were not defined in the study and may be related to industrial burning, residential burning or a combination of both.
- A risk assessment was conducted for Tangshan, a heavily polluted city in China, for cumulative (i.e., individual species concentrations summed) PAH (PM bound) exposure in ambient air for three age groups (1-11 years; 12-17 years; 18-70 years) (Zhang et al. 2019). The study found that exposure to PAHs in ambient increased the incremental lifetime cancer risk for all age/gender groups above the acceptable risk level (above $1x10^{-6}$ target level), with adults having the highest risk increase. PAH concentrations in ambient in the study area were determined to be related to coal combustion, vehicular exhaust and biomass burning (Zhang et al. 2019). It is noted that coal combustion sources of PAHs were not defined in the study area; however, it is stated that the sampling location in the study was within 50 km of a coal-fired power plant.
- A laboratory study applied $PM_{2.5}$, at concentrations derived from monitoring at a biomass-fired power generation plant, to human genome arrays, bioinformatic analysis and immunoblotting to determine the effect of $PM_{2.5}$ on gene regulation in lung epithelial cells. The study found that $PM_{2.5}$ altered the regulation of 175 genes related to cellular development, metabolism, inflammation, cancer and immune response (Popadić et al. 2018). The $PM_{2.5}$ contained a low concentration of PAHs comprised of 55 PAH species. Due to the low concentration and complex PAH mixture, the study could not fully assess the influence of PAHs on PM-mediated gene responses but did identify that a PAH-activated transcription factor was stimulated during $PM_{2.5}$-mediated signalling (Popadić et al. 2018).

Classification: Protected A

- A risk assessment carried out for flue-gas emissions at three coal-fire power plants in Huainan, China evaluated risks to plant workers from PAHs via inhalation and dermal contact with particulates (Wang et al. 2015). Risks to nearby residents was also considered through collection of outdoor air samples near the gates of the power plants. The study calculated risks using total PAH exposure and found that exposure to PAHs in by workers and nearby residents by both the inhalation and dermal contact pathway increased the incremental lifetime cancer risk above the acceptable risk level ($1x10^{-4}$ to $1x10^{-5}$ versus $1x10^{-6}$ target level) (Wang et al. 2015).

- PM-bounded PAH concentrations in $PM_{2.5}$ ambient air samples collected in six sites in Guangzhou, China were evaluated to determine their composition, relative toxicity of the various PAH components, and carcinogenic risk (Gao et al. 2015). The carcinogenic potencies of individual PAHs were calculated using Toxic Equivalency Factors (TEFs), and a generic equation was used to identify an incremental lifetime cancer risk for total PAH exposure. The study found that the inhalation lifetime cancer risk was above the acceptable risk level ($1x10^{-4}$ versus $1x10^{-6}$ target level) (Gao et al. 2015). It is noted that risks from PAHs in the study were not solely sourced from power plants/energy generation, however coal combustion was determined to be the most significant source of PAH emissions in the study, followed by biomass burning and vehicular emissions.

- $PM_{2.5}$-bounded PAH concentrations in ambient air samples collected in Beijing, a Chinese megacity, were evaluated to determine their source, and source-based cancer risk calculations were completed (Chao et al. 2019). The assessment of carcinogenic risk from coal combustion, associated with regional transport from surrounding areas in which coal-fired power plants are present, found that cancer risks (assuming a 30-year exposure over a 70-year lifetime) were within generally acceptable target risk levels (i.e., $1x10^{-7}$ versus target level of $1x10^{-6}$) (Chao et al. 2019). It is noted that the coal combustion emissions are likely a result of both residential and power generation-related burning.

- A study in which soil samples were collected from across Shanghai, China, determined that the sources of PAH concentrations in soil were (in descending order) coke tar-related activities, vehicular emissions and coal combustion, creosote, biomass burning and natural sources (Wang et al. 2013). Two of the sample sites with the highest concentrations of PAHs were sampled near a coal-fired power plant. Benzo[a]pyrene TEFs were used to estimate total carcinogenic PAH concentrations which were compared by the authors of the study to adjusted Canadian soil quality guidelines for protection of direct contact risks to humans and the environment from the Canadian Council of Ministers of the Environment (CCME). Twenty-seven out of 57 soil samples collected had concentrations above the CCME safe value (0.6 milligram per kilogram [mg/kg^{-1}]), with exceeding soil locations attributed to proximity to a coal-fired power plant, traffic or industrial activities. An index of additive cancer risk was calculated to assess risks to potable groundwater from leaching of PAHs in soil. The average index of additive cancer risk across the samples was approaching the safe limit of 1, and 17 out of 57 samples were above the safe limit of 1 (Wang et al. 2013).

- $PM_{2.5}$-bounded PAH concentrations in ambient air samples collected in Xi'an, a large Chinese city, from nine communities were evaluated to determine potential increased cancer risks to residents over a lifetime inhalation exposure (i.e., 70 years) (Xu et al. 2016). A thermal power generation plant was noted to be present in the study area. Benzo[a]pyrene TEFs were used to estimate total carcinogenic PAH concentrations, and the study found that exposure to $PM_{2.5}$-bounded PAH concentrations in ambient air could result in eight in one million people developing cancer in the study area due to inhalation of $PM_{2.5}$-bounded PAHs. It is noted that risks from PAHs in the study were not solely sourced from power

Classification: Protected A

plants/energy generation, and the estimated increase in cancer incidence could not be linked to power generation alone.

- PM-bounded PAH concentrations in ambient air samples collected in cities across China in previous studies were evaluated in a literature review of data from 2001-2016 and used to carcinogenic risk from inhalation in various regions (Yan et al. 2019). The study found that air pollution was higher in northern cities than in southern cities. Sources of PM-bounded PAH concentrations in ambient air included coal combustion (residential and industrial/power generation), coking activities, biomass burning, vehicular emissions and petroleum activities. TEFs were used to estimate total carcinogenic PAH concentrations and the study found that the inhalation lifetime cancer risks were above the acceptable risk level (1×10^{-6} target level) for a significant portion of cities for all age groups considered (children and adolescents 0-14 years, adults 15-64 years, seniors >64 years). Cancer risks were higher in the northern cities and adults were determined to be at the highest risk across cities. The cancer risk to females was determined to be marginally higher than males for the child, adolescent and senior age groups (Yan et al. 2019).

Ecological Effects

Abiotic

No new literature retained for evaluation.

Biotic

No new literature retained for evaluation.

It is noted that one study evaluated concentrations of PAHs in clams found in contaminated sediment and completed an ecotoxicological risk assessment (as well as a human health risk assessment for clam ingestion). However, the contamination in the sediment and subsequently in clams was not indicated to be related to electricity generation.

4.6 New Substances

Seven studies were identified in white literature related to new substances not already listed under Category 1, 2, 3 or 4 substances related to electricity generation. Of these studies, none were considered to be relevant for further evaluation in relation to new substances. Four of the studies were not retained for evaluation because health effects were not described. The focus of these studies was the efficacy, life-cycle of substances and/or emissions characteristics associated with novel power generation techniques. One study was not retained for evaluation as it was not available in an English translation (original study reported in Japanese). Two studies were determined to be irrelevant to the topic of new substances.

Classification: Protected A

4.7 Data Gaps

Based on the data gaps identified in previous Five-Year Reviews, the literature search also considered public health and ecological effects associated with the following:

- Effects of mixtures;
- Effects of low doses over long periods of time: Golder has interpreted that this refers to the evaluation of chronic exposures, defined by Health Canada[10] as greater than 90 days;
- Long- and short-range dispersion and deposition.

The search methodology for identifying studies and articles related to these topics is outlined in Sections 3.1 and 3.2, and relevant findings are provided below.

4.7.1 Effects of Mixtures

Three studies were identified in the white literature following a specific search related to the effect of mixtures of Category 1, 2 and 3 substances related to electricity generation. Of these studies, two were considered to be relevant and were retained for further evaluation and both were of moderate-strong quality. One was not retained for evaluation because the health effects described in the study were not specifically related to electricity generation.

- A laboratory study applied $PM_{2.5}$-bounded PAH emissions, at concentrations derived from monitoring a biomass-fired power generation plant, to human genome arrays, bioinformatic analysis and immunoblotting to determine the effect of $PM_{2.5}$ on gene regulation in lung epithelial cells. The study found that $PM_{2.5}$ altered the regulation of 175 genes related to cellular development, metabolism, inflammation, cancer and immune response (Popadić et al. 2018). The $PM_{2.5}$ contained a low concentration of PAHs comprised of 55 PAH species. Due to the low concentration and complex PAH mixture the study could not fully assess the influence of PAHs on PM-mediated gene responses but did identify that a PAH-activated transcription factor was stimulated during $PM_{2.5}$-mediated signalling (Popadić et al. 2018).
- Another study used evaluated the association between $PM_{2.5}$-associated pollutant mixtures and with the number of non-accidental deaths reported daily from 1999-2006 in the greater Boston area. $PM_{2.5}$ samples were analyzed to determine their composition, and sample days with similar compositions were clustered and compared to number and causes of death on the corresponding days. Results of the study indicated that an increase of 10 µg/m^3 of $PM_{2.5}$ over one and two days resulted in increased mortality of 1.1 to 2.3%, and this increased mortality was elevated to 3.7% where the $PM_{2.5}$ was comprised of a mixture of pollutants with a high concentration of traffic and oil-combustion related substances (Zanobetti et al. 2014).

[10] Health Canada. 2010. Federal Contaminated Site Risk Assessment in Canada, Part V: Guidance on Human Health Detailed Quantitative Risk Assessment for Chemicals ($DQRA_{Chem}$). September 2010. Contaminated Sites Division, Safe Environments Directorate.

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It is noted that the white literature review identified a trend wherein numerous metals were often evaluated in a single study. However, health effects were individually evaluated for each metal in these studies rather than combined/cumulative effects.

It is also noted that the white literature review identified some studies which evaluated the combined health risk for a number of PAHs. These studies were completed as risk assessments which summed exposure concentrations for individual PAHs to calculate risks for cumulative PAH exposure. These studies have been evaluated and summarized in Section 4.5.7 above for PAHs. A list of these PAH-mixture studies has been compiled and is included as Appendix D1.

Three grey literature studies were related to the effects of mixtures on human health for Category 1, 2, and 3 substances and electricity generation and are summarized below.

- A 2018 EPRI study evaluated emission estimates and associated risks to human health for 324 coal-fired power plants in the United States that were projected to be in operation in 2017 following implementation of air pollution controls pursuant to the Mercury and Air Toxics Standards regulation (EPRI 2018). EPRI conducted a human health risk assessment based on modelled 1-hour average ground level concentrations and long-term average concentrations of emissions. The study evaluated emissions from large number of stack-gas constituents and three types of inhalation risks: chronic non-cancer, acute non-cancer, and cancer risk. The chronic toxic endpoint was evaluated assuming continuous exposure for at least 1 year while the acute toxic endpoints were evaluated using peak 1-hour concentrations. Cancer risks were evaluated assuming a lifetime (i.e., 70 years) of continuous exposure.
  - The tier 1 inhalation risk modelling applied a generic set of meteorological conditions to estimate the max 1-hour average and maximum long-term average concentrations. The tier 2 inhalation risk modelling applied a less conservative detailed modelling approach that accounted for a full year of meteorology data. Based on the more conservative air emissions modelling (tier 1 method), 100% of power plants were below the US EPA acceptable risk from short-term exposure (i.e., hazard quotients <1), while 98% of power plants were below the US EPA's acceptable chronic non-cancer risk threshold (i.e., hazard quotient <1) and 53% were below the US EPA's acceptable cancer risk threshold (i.e., incremental lifetime cancer risk $<1x10^{6}$). Arsenic, chromium VI, and nickel accounted for 90% of the modeled cancer risk on average. Chlorine, acrolein, and arsenic accounted for the 80% of the modeled chronic non-cancer risk on average. Arsenic and cadmium had the highest acute risk. Based on the tier 2 inhalation risk modelling, all power plants were associated with risks below the US EPA's acceptable risk thresholds. The parameters contributing to the most risk in the tier 2 assessment included arsenic, chromium (VI), nickel, chlorine, and acrolein.
- A case study conducted by the Environmental Integrity Project (EIP) found a potential association between reduced asthma hospitalization rates in 2009 and 2010 and a steep reduction in air emissions (sulphur oxides, NO_x, and PM_{10}) by two coal-fired power plants in two zip codes within the City of Baltimore (EIP 2017). The EIP found that the reduced asthma hospitalization rates in 2009 and 2010 coincided with a rapid drop in emissions between 2009 and 2010. Two coal-fired power plant introduced new pollution controls to its two coal-fired boilers that reduced sulphur oxide emissions by 44,792 tons, NO_x emissions by 9,945 tons, and PM_{10} emissions by 546 tons. However, it should be noted that the report found multiple variables that correlated with asthma trends over time: specifically, poverty and median household income.

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- The California Office of Environmental Health Hazard Assessment (OEHHA) examined the relationship between greenhouse gas (GHG) emissions and emission of toxic air pollutants that could result in human exposure (OEHHA 2017). They examined a total of 281 GHG-producing facilities in the State of California, 76 of which were electricity generation facilities. Emissions data were weighted using the toxicity of the emitted chemicals as a proxy for potential exposures. The correlation analysis found electricity generation facilities and GHGs emissions showed low degree of correlation with toxicity-weighted emissions, and when the data was log-transformed there was a moderate but significant correlation. The authors noted that emissions across electrical generating facilities varied broadly. By comparison, toxicity weighted emissions from oil refineries had a high positive correlation with GHGs, whereas oil and gas production facilities and cement plants were moderately correlated.
- Anderson et al. (2013) adapted the model developed by the Canadian Medical Association to estimate the human health impacts from coal-fired electrical generation in Alberta. The model correlated health impacts due to PM and ozone to population densities and forecasts, and estimated health damages in terms of premature deaths, asthma symptom days, hospital admissions, and emergency room visits. The model also accounted for the lifetime (i.e., closing) of coal-fired power plants in Alberta. Overall, predicted annual rates of premature death, hospital admissions, and emergency room visits were highest for people over the age of 65. In addition, rates of hospital admissions due to respiratory illness were also high for young children under the age of 4. Estimated annual numbers of premature deaths, asthma symptom days, hospital admissions and emergency room visits were higher in 2020 compared to 2008 but lower in 2031 compared to 2008 and 2020, which the authors attributed to the closing of several of the coal-fired power plants included in the modelling. Between 2008 and 2031, the authors predicted coal-fired power plant emissions of PM and ozone would result in: 420 premature deaths due to acute exposure, 3,085 premature deaths due to long-term exposure, 897 hospital admissions due to respiratory illnesses, 1,209 hospital admissions due to cardiovascular illness, 5,666 emergency department visits due to respiratory illness, 13,229 emergency department visits due to cardiovascular illness, and 105,527 asthma symptom days.

Table 23: Key Effects of Mixtures Studies

Author	Year	Title	Ranking(1)
White Literature			
Popadić, Désirée; Heßelbach, Katharina; Richter-Brockmann, Sigrid; Kim, Gwang-Jin; Flemming, Stephan; Schmidt-Heck, Wolfgang; Häupl, Thomas; Bonin, Marc; Dornhof, Regina; Achten, Christine; Günther, Stefan; Humar, Matjaz; Merfort, Irmgard	2018	Gene expression profiling of human bronchial epithelial cells exposed to fine particulate matter (PM2.5) from biomass combustion.	Moderate-Strong
Zanobetti, Antonella; Austin, Elena; Coull, Brent A.; Schwartz, Joel; Koutrakis, Petros	2014	Health effects of multi-pollutant profiles	Moderate-Strong
Grey Literature			
Electric Power Research Institute	2018	Hazardous air pollutants (HAPs) emission estimates and inhalation human health risk assessment for U.S. coal-fired electric generating units: 2017 base year post-MATS evaluation	Strong

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Author	Year	Title	Ranking(1)
Office of Environmental Health Hazard Assessment, California Environmental Protection Agency	2017	Tracking and evaluation of benefits and impacts of greenhouse gas limits in disadvantaged communities: Initial report	Moderate-Strong
Environmental Integrity Project	2017	Asthma and air pollution in Baltimore City	Weak
Kristi Anderson, Tim Weis, Ben Thibault, Farrah Khan, Beth Nanni, Noah Farber	2013	A costly diagnosis: Subsidizing coal power with Albertans' Health	Moderate-Strong

Notes:
Ranking is based on degree to which information in an article meets specific criteria. Ranking Checklists are presented in APPENDIX C. Total possible score = 28 - (number of "n/a" * 2), where n/a means non-applicable criteria
Studies were considered to be weak (i.e., of low quality) if the total calculated score was ≤50%, moderate-weak if the total calculated score was 51-65%, moderate-strong if the total calculated score was 65-79% and strong (i.e., of high quality) if the total calculated score was ≥80%.
Links to the articles are provided in APPENDIX E.

4.7.2 Effects of Low Doses Over Long Periods of Time

Golder understood the topic of low doses over long periods of time to involve evaluation of chronic exposures, defined by Health Canada (2010)[11] as greater than 90 days. Six studies were identified in white literature following a specific search related to chronic exposures to Category 1, 2 and 3 substances related to electricity generation. Following review of the full texts of each study, two were considered to be relevant and were retained for further evaluation, with one of high quality and one of moderate-weak quality. It is noted that the one of the four studies, which was not summarized below, was evaluated via the Checklist in APPENDIX C. The studies excluded from the evaluation were ruled out based on a) focus on emissions and health effects from vehicular emissions instead of electricity generation, b) focus on emissions and heath effects from drilling for natural gas instead of electricity generation, and c) lack of focus on chronic exposure health effects.

- A study of the health effects (and associated costs) from exposure to PM, CO, SO_2 and NO_x emissions from a gas-fired power plant found that the most significant health effect was restricted activity days attributed to nitrate emissions and the costliest health effects included restricted activity days, mortality, and chronic bronchitis. Overall, emissions of PM, CO, SO_2 were determined to be low, and NOx was responsible for the majority of emissions and resultant health effects (Fouladi-Fard et al. 2016).
- A literature review of limited studies available from China summarized findings related to respiratory effects associate with air pollution, characterized by SO_2, CO, lead, NO_2, $PM_{2.5}$ and PM_{10}. The literature review focused on respiratory effects including asthma (air pollution determined to increase onset and prevalence), chronic obstructive pulmonary disease (air pollution determined to increase onset and prevalence) and lung cancer (air pollution determined to be a major risk factor for lung cancer incidence) (Guan et al. 2016). Sources of air pollution in China as summarized by the literature review included vehicular emissions, biomass burning, industrial emissions and power generation, therefore risks are not solely associated with power plants/power generation.

It is noted that the beyond the specific search results related to chronic exposure, the general literature review for new information for Category 1, 2, and 3 substances related to electricity generation identified some studies which included chronic exposure periods. These studies have been evaluated and summarized in Section 4.0 above for the substance(s) on which the study focused. A list of these chronic exposure studies has been compiled and is included as Appendix D2.

[11] Health Canada. 2010. Federal Contaminated Site Risk Assessment in Canada, Part V: Guidance on Human Health Detailed Quantitative Risk Assessment for Chemicals ($DQRA_{Chem}$). September 2010. Contaminated Sites Division, Safe Environments Directorate.

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Two studies were identified in the grey literature related to health effects of low doses over long periods.

- A 2018 EPRI study evaluated emission estimates and associated risks to human health for 324 coal-fired power plants in the United States that were projected to be in operation in 2017 following implementation of air pollution controls pursuant to the Mercury and Air Toxics Standards regulation (EPRI 2018). EPRI conducted a human health risk assessment based on modelled long-term average concentrations of emissions. The study evaluated emissions from large number of stack-gas constituents and three types of inhalation risks: chronic non-cancer and cancer risk. The chronic toxic endpoint was evaluated assuming continuous exposure for at least 1 year. Cancer risks were evaluated assuming a lifetime (70 years) of continuous exposure.
  - The tier 1 inhalation risk modelling applied a generic set of meteorological conditions maximum long-term average concentrations. The tier 2 inhalation risk modelling applied a less conservative detailed modelling approach that accounted for a full year of meteorology data. Based on the more conservative air emissions modelling (tier 1 method), 98% of power plants were below the US EPA's acceptable chronic non-cancer risk threshold and 53% were below the US EPA's acceptable cancer risk threshold. Arsenic, chromium VI, and nickel accounted for 90% of the modeled cancer risk on average. Chlorine, acrolein, and arsenic accounted for the 80% of the modeled chronic non-cancer risk on average. Based on the tier 2 inhalation risk modelling, all power plants were associated with risks below the US EPA's acceptable risk thresholds. The parameters contributing to the most risk in the tier 2 assessment included arsenic, chromium (VI), nickel, chlorine, and acrolein.
- Anderson et al. (2013) adapted the model developed by the Canadian Medical Association to estimate the human health impacts from coal-fired electrical generation in Alberta. The model correlated health impacts due to PM and ozone to population densities and forecasts, and estimated health damages in terms of premature deaths due to chronic and acute exposure. The model also accounted for the lifetime (i.e., closing) of coal-fired power plants in Alberta. Premature deaths due to chronic exposure was estimated to be 8-times higher than the premature deaths predicted due to acute exposure. Anderson et al. (2013) predicted 3,085 premature deaths between 2008 and 2031 due to long-term and acute exposure combined.

Table 24: Key Effects of Low Doses Over Long Periods of Time Studies

Author	Year	Title	Ranking(1)
White Literature			
Fouladi-Fard, Reza; Naddafi, Kazem; Yunesian, Masud; Nabizadeh Nodehi, Ramin; Dehghani, Mohammad; Hassanvand, Mohammad	2016	The assessment of health impacts and external costs of natural gas-fired power plant of Qom.	High
Guan, Wei-Jie; Zheng, Xue-Yan; Chung, Kian Fan; Zhong, Nan-Shan	2016	Impact of air pollution on the burden of chronic respiratory diseases in China: time for urgent action	Moderate-Weak
Grey Literature			
Electric Power Research Institute	2018	Hazardous air pollutants (HAPs) emission estimates and inhalation human health risk assessment for U.S. coal-fired electric generating units: 2017 base year post-MATS evaluation	Strong

Author	Year	Title	Ranking(1)
Kristi Anderson, Tim Weis, Ben Thibault, Farrah Khan, Beth Nanni, Noah Farber	2013	A costly diagnosis: Subsidizing coal power with Albertans' Health	Moderate-Strong

Notes:
Ranking is based on degree to which information in an article meets specific criteria. Ranking Checklists are presented in Appendix C. Total possible score = 28 - (number of "n/a" * 2), where n/a means non-applicable criteria
Studies were considered to be weak (i.e., of low quality) if the total calculated score was ≤50%, moderate-weak if the total calculated score was 51-65%, moderate-strong if the total calculated score was 65-79% and strong (i.e., of high quality) if the total calculated score was ≥80%.
Links to the articles are provided in APPENDIX E.

4.7.3 Long- and Short-Range Dispersion and Deposition

Nine studies were identified in white literature and four studies were identified in the grey literature following a specific search related to long- and short-range dispersion and deposition of Category 1, 2 and 3 substances from electricity generation. Of the 13 studies identified, none were considered to be relevant for human and/or ecological health effects related to electricity generation. The 13 studies were not retained for evaluation as they did not discuss health effects. The studies were not ranked according to the Checklist nor were the results summarized. However, the studies may be of interest to CASA as they address long- and short-range dispersion and deposition of emissions in general. A list of these long- and short-range dispersion and deposition studies, including those identified in the specific search for long- and short-range dispersion studies, has been compiled and is included as Appendix D3.

- In general, the identified studies discussed changes in concentrations and composition of emissions with increasing distance from an emissions source.
- In general, the identified studies included common influencers of emission transport, dispersion and deposition such as local weather conditions (e.g., precipitation), climate (e.g., humidity) and wind.

4.7.4 Additional Studies of Interest

During the literature review, Golder identified a number of studies which did not meet the search criteria of the scope of work but were flagged as potentially interesting to CASA. A list of such studies is provided below.

Table 25: Studies Flagged for Interest

Author	Year	Title	Summary
Wei Chen, Jinglan Hong, Xueliang Yuan, Jiurong Liu	2015	Environmental impact assessment of monocrystalline silicon solar photovoltaic cell production: a case study in China	Comparison of the environmental impact of manufacturing photovoltaic cells compared to the impact of coal-burning.
Environmental Integrity Project	2018	Dirty deception: How the wood biomass industry skirts the Clean Air Act	Emissions and permit violations from wood pellet manufacturing plants, ultimately for biomass combustion. Methanol is reported as a hazardous air pollutant emitted from wood pellet production facilities and is not included in Category 1, 2, 3, or 4.
Electric Power Research Institute	2020	Air pollutants and toxics: Health effects (PS203B), October 2020	Newsletter summarizing announcements, research updates, peer-reviewed scientific literature, and other relevant news items. Cost is $5,000 USD.

Author	Year	Title	Summary
	2020	PS203C: Air quality and multimedia characterization, assessment and health newsletter, May 2020	Semi-annual newsletter summarizing research, key published papers, and news items related to stationary source characterization, and multimedia fate of pollutants. cost is $5,000 USD.
	2020	Air pollutants and toxics: assessments and models (PS203A) newsletter, April 2020	Semi-annual newsletter summarizing research, key published papers, and news items related to air quality assessments, ambient measurements, and models. Cost is $5,000 USD.
	2020	Overview of emissions impacts from grid-connected battery energy storage	Effects of energy storage operation on greenhouse gases and air pollutants. Cost is $5,000 USD.
	2019	Human health effects at low particulate matter concentrations: supralinearity response	Evaluation of supralinearity response (i.e., greater effects at lower levels) in epidemiological studies due to exposure to $PM_{2.5}$. Cost is $10,000 USD.
	2018	Program on technology innovation: Environmental aspects of natural gas — Current state of science, knowledge gaps and opportunities for future research	Evaluation of current understanding and research gaps associated with environmental and human health impacts of the natural gas value chain. Cost is $500 USD.
	2017	Interim update on medicare project: Evaluation of the long-term health effects of air pollution	Evaluation of numerus long-term epidemiological studies on the association between air pollution and adverse human health effects. Cost is $2,500 USD.

5.0 CONCLUSION

Based on the search methodology outlined in Sections 3.1 and 3.2, a total of 2,273 white literature articles and 175 grey literature articles were initially identified. Based on a title search, 399 white literature articles were retained for further abstract review. Following abstract review, 47 white literature articles were retained for article ranking and evaluation using the Checklist, and 37 were retained following ranking and have been summarized herein. Following abstract/summary review of the grey literature, 26 reports were initially considered, and following report review only five were retained for evaluation and ranking. Of the 47 white literature studies evaluated, only one was related to ecological endpoints while the remainder evaluated human health effects. Of the five grey literature reports evaluated, all five were related to human health effects. Studies retained for evaluation were limited in subject to select Category 1 substances (PM, mercury, NO_2, SO_2, ozone), select Category 2 metals and select Category 3 metals and PAHs). A significant amount of effort was put into carrying out the grey literature searches and in the end, only five were retained for evaluation and ranking. The majority of grey literature articles were not original studies or contained information that generalized the health effects of substances without specific reference to studies. Golder recommends that future literature reviews focus on peer-reviewed white literature.

- For Category 1 substances, studies retained for evaluation included both human health risk assessments and studies focusing on specific health endpoints (e.g., respiratory effects, diabetes occurrence). Studies retained for evaluation for Category 2 and 3 substances were generally human health risk assessments evaluating the likelihood of increased incremental lifetime cancer risk. It is of note that for Category 2 and 3 metals, studies retained for evaluation often considered multiple metals, however effects and risks were individually assessed for each metal in the study. As a result, some studies are summarized for multiple substances.

- Of the ecological studies reviewed, the majority focused on evaluating absorption and uptake of various substances emitted into the air from electricity generation by vegetation species. These studies outlined the relative concentrations of substances from electricity generation-related sources in vegetation but did not evaluate ecological health endpoints (e.g., reduced growth) in vegetation.
- Of the studies rejected following abstract review due a lack of discussion of health effects and/or relevance to electricity generation, a number of common topics that were studied were identified:
  - Emission characteristics/chemical profiles of emissions.
  - Investigations into efficacy and/or efficiency of energy generation processes and efficacy of novel and existing emission control techniques.
  - Health effects from residential exposure to emissions such as wood and coal burning within the home, or health effects from emissions due to solder, gun ranges, cement plants, manufacturing plants and other non-energy generation-related emissions.
  - Early stages of energy generation such as natural gas locating, drilling and well development.
  - Health effects related to coal mines (e.g., exposure to dust from coal mines, exposure to run-off water from coal mine waste pits).
  - Health costs (e.g., economic impact of increased hospitalizations) or relative toxicity of substances without description of health effects for the substances.
  - Human and/or ecological risks in urban areas subject to multiple sources of emissions (e.g., vehicular exhaust, residential biomass burning, industrial/manufacturing emissions and power generation emissions) wherein it was not possible to determine the health effects directly correlated with electricity generation. These studies were not retained for further evaluation unless it could be clearly discerned that electricity generation were a major source of emissions in the evaluation.
  - Impact of implemented emission policies on air quality over time.

Searches for new substances not already listed under Category 1, 2, 3 or 4 were conducted. Seven white literature studies were identified through the search; however, none were considered to be relevant for further evaluation in relation to new substances. Out of the175 studies identified in the grey literature search, none were retained for evaluation.

Three studies were identified in white literature following a specific search related to the effect of mixtures. Of these studies, two were considered to be relevant and were retained for further evaluation. It is noted that the literature review identified a trend wherein numerous metals were often evaluated in a single study, with PAHs often included in the study as well and evaluated as a group. However, metals and/or PAH health effects were individually evaluated in these studies rather than combined/cumulative effects. Three studies were identified in grey literature related to the effect of mixtures and were retained for further evaluation. The relevant studies were summarized for consideration by CASA.

Six studies were identified in white literature following a specific search related to the effect of low doses over long periods of time, which Golder has interpreted that this refers to the evaluation of chronic exposures, defined by

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Health Canada[12] as greater than 90 days. Of the six studies identified, two were considered to be relevant and were retained for further evaluation. It is noted that beyond the specific search returns related to chronic exposure, the general white literature review for new information for Category 1, 2 and 3 substances related to electricity generation identified some studies which included chronic exposure periods. One study was identified in grey literature related to the effect of low doses over long periods of time and was retained for further evaluation. The relevant studies were summarized for consideration by CASA.

Nine studies were identified in white literature following a specific search related to long- and short-range dispersion and deposition. Of the nine studies identified, none were considered to be relevant for human and/or ecological health effects related to electricity generation. However, the studies may be of interest to CASA as they address long- and short-range dispersion and deposition of emissions in general. It is also noted that beyond the specific search returns related to long- and short-range dispersion and deposition, the general literature review for new information for Category 1, 2 and 3 substances related to electricity generation identified a number of studies which were flagged as potentially of interest for CASA with relation to long- and short-range dispersion and deposition. The relevant studies were summarized for consideration by CASA.

- In general, the identified studies discussed changes in concentrations and composition of emissions with increasing distance from an emissions source.
- In general, the identified studies included common influencers of emission transport, dispersion, and deposition such as local weather conditions (e.g., precipitation), climate (e.g., humidity) and wind.

[12] Health Canada. 2010. Federal Contaminated Site Risk Assessment in Canada, Part V: Guidance on Human Health Detailed Quantitative Risk Assessment for Chemicals ($DQRA_{Chem}$). September 2010. Contaminated Sites Division, Safe Environments Directorate.

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Golder Associates Ltd.

Grace Daly, M.Sc., BIT
Environmental Scientist

Amica Ferras, M.Env.Sc.
Risk Assessor

Andrea Amendola, H.B.Sc., QPRA
Senior Toxicologist & Risk Assessor

Audrey Wagenaar, M.Sc., DABT, PChem, CSAP
Associate, Senior Environmental Scientist

GD/AF/AA/AW/asd

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Classification: Protected A

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Classification: Protected A

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Classification: Protected A

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Classification: Protected A

APPENDIX A

Substances Included in Literature Review

APPENDIX A
Substances Included in Literature Review

Category	Substance
Category 1: Priority List	Total Particulate Matter ($PM_{2.5}$ and Total Suspended Particles [TSP])
	Mercury
	Sulphur Dioxide (SO_2)
	Nitrogen Dioxide (NO_2)
	Greenhouse Gases (GHGs)
Category 2: Management Actions Need to be Considered	Antimony
	Arsenic
	Barium
	Cadmium
	Cobalt
	Lead
	Manganese
	Selenium
	Chromium III and VI
	Formaldehyde
	Benzene
	Hydrogen fluoride
Category 3. Ongoing Surveillance	Boron
	Calcium
	Chlorine
	Copper
	Iron
	Magnesium
	Molybdenum
	Potassium
	Rubidium
	Silicon
	Silver
	Sodium
	Strontium
	Thallium
	Thorium
	Titanium
	Uranium
	Zinc
	Zirconium
	5-Methylchrysene
	7,12-Dimethylbenz(a)anthracene
	2-Chloroacetophenone
	Aluminum
	Beryllium
	Bromine
	Nickel
	Phosphorous
	Vanadium
	2,3,7,8-Tetrachlorodibenzodioxin (TCDD) and 2,3,7,8-Tetrachlorodibenzofuran (TCDF)
	Hydrogen chloride
	2,4-Dinitrotoluene
	3-Methylcholanthrene
	Acetaldehyde
	Acrolein
	Benzyl Chloride
	Bis(2-ethylthexyl)phthalate
	Ethylbenzene
	Hexachlorobenzene
	Propylene Oxide
	Ammonia (NH_3)
	Sulphuric Acid
	Polycyclic Aromatic Hydrocarbons (PAHs) (akylated PAHs: 2-methylfluorene and 2-methylnaphthalene; and chlorinated PAH: 2-chloronaphthalene)

APPENDIX B

White and Grey Literature Review Search Terms

Classification: Protected A

Table B1: White Literature Staked Search Strategy

Stacked Search Category	Search Terms and Operator(s)	Search Field
General	air quality OR air pollution OR air contamination	All text or Title
Industry	(power OR energy) AND generation	All text or Title
Energy Type	(coal OR natural gas OR wind OR biomass OR solar OR fuel oil OR Energy) AND air emission*	All text or Title
Receptor	Human Health OR Public Health OR Health OR Tox* OR Impact OR Environment OR Eco* OR Plant OR Veg* OR Tree OR Forest OR Flora OR Fauna OR Bird OR Avian OR Wildlife OR Mammal* OR Benthic Invertebrate* OR Microbe* OR Fish OR Lichen OR Moss OR Amphibian*	All text or Title
Subtance-Specific Operators		
Category 1	Particulate matter OR PM* OR TSP	Title
	Mercury	Title
	SO2 OR Sulphur Dioxide	Title
	NOx* OR NO2 OR Nitrogen Dioxide OR Nitrogen	Title
	Greenhouse	Title
Category 2	Heavy Metal*	Title
	Antimony OR Sb OR Arsenic OR As OR Barium OR Ba OR Cadmium OR Cd OR Cobalt OR Lead OR Pb OR Manganese OR Mn OR Selenium OR Se OR Chromium OR Cr OR Formaldehyde OR Hydrogen Fluoride OR HF	Title
Category 3	Heavy Metal*	Title
	Boron OR Calcium OR Chlorine OR Chlor* OR Copper OR Iron OR Magnesium OR Potassium OR Rubidium OR Silicon OR Sodium OR Strontium OR Silver OR Thallium OR Thorium OR Titanium OR Uranium OR Zinc OR Zirconium OR Aluminum OR Beryllium OR Bromine OR Nickel OR Phosphorus OR Vanadium	Title
	Hydrogen chloride OR HCL OR NH3 OR Ammonia OR Ammon* OR Sulphuric Acid OR H2SO4 OR methylchrysene OR dimethylbenz(a)anthracene OR anthracene OR Chloroacetophenone OR TCDD OR TCDF OR tetrachlorodibenzofuran OR dioxin OR dinitrotoluene OR methylcholanthrene OR Acetaldehyde OR Acrolein OR Benzyl Chloride OR phthalate OR Ethylbenzene OR Hexachlorobenzene OR Propylene Oxide OR methylfluorene OR methylnaphthalene OR chloronaphthalene	Title
Datagap-Specific Operators		
Effects associated with low doses over long periods of time	Low Dose OR OR Chronic OR Prolonged	All text
	Chronic Effects of Air Pollution from Energy Plants	All text
Effects associated with mixtures	Mixture* AND Effect	All text
	Synerg* air pollution from power plants	All text
Effects associated with long- and short-range dispersion and eposition	Dispersion OR Deposition OR Transport	All text
New substances/groups of substances emitted by p	Emerging OR Novel OR Contaminant* of Concern	All text
	Novel energy emission health effects	All text

Notes:

Stacked searches were conducted in EBSCO Discovery Service Database

Stacked searches with performed with AND

Search field was modified to narrow down the list of results, depending on the individual search

Table B2: Grey Literature Google Based Agency Searches

Agency Name	Agency-Specific Operator (URLs)
Air Impacts	Airimpacts.org
Alberta Environment	.gov.ab.ca
British Columbia Ministry of Environment and Climate Change	.gov.bc.ca
Brookhaven National Laboratory	.bnl.gov
Canadian Clean Power Coalition	canadiancleanpowercoalition.com
Clean Air Strategic Alliance (CASA)	casahome.org
Clean Air Task Force	catf.us
Commission for Environmental Cooperation	cec.org
Environment America	environmentamerica.org
Environment and Climate Change Canada	canada.ca
Environmental Integrity Project	environmentalintegrity.org
European Commission – Environment	.ec.europa.eu/environment
Geological Survey of Canada	nrcan.gc.ca
Government of British Columbia	.gov.bc.ca
Government of Ontario	.gov.on.ca
Government of Saskatchewan	.gov.sk.ca
Greenpeace	.greenpeace.org
Greenpeace Canada	.greenpeace.ca
Health Canada	canada.ca
Health Effects Institute	healtheffects.org
International Joint Commission	ijc.org
National Council on Air and Stream Improvement	ncasi.org
National Energy Technology Laboratory	netl.doe.gov
Natural Resources Canada	nrcan.gc.ca
New South Wales Health	.nsw.gov.au
Ontario Clean Air Alliance	cleanairalliance.org
Ontario Ministry of the Environment, Conservation, and Parks	ministry-environment-conservation-parks
Ontario Power Generation	opg.com
Southwest Clean Air Agency	swcleanair.org
Sustainable Energy & Economic Development	seedcoalition.org
Toronto Public Health	toronto.ca
United Nations Economic Development	unep.org
World Resources Institute	wri.org
Union of Concerned Scientists	ucsusa.org

Notes:
The agencies in the table above were searched using google by combining search operators with the Agency-specific Operator

APPENDIX C

Study Review Checklists

Classification: Protected A

Title: A Costly Diagnosis: Subsidizing coal power with Albertans' health
Author: Kristi Anderson, Tim Weis, Ben Thibault, Farrah Khan, Beth Nanni, Noah Farber

Checklist for Assessing the Quality of Quantitative Studies[1]

	Criteria	Yes (2)	Partial (1)	No (0)	N/A
1	Question / objective sufficiently described?	Yes			
2	Study design evident and appropriate ?	Yes			
3	Method of subject/comparison group selection or source of information/input variables described and appropriate ?	Yes			
4	Subject (and comparison group, if applicable) characteristics sufficiently described?				N/A
5	If random allocation was possible, was it described?				N/A
6	If blinding of investigators/subjects was possible was it reported?				N/A
7	Exposure measure(s) well defined and robust to meaesement /misclassification bias? Means of assessment reported?				N/A
8	Outcome well defined and robust to measurement/misclassification bias? Means of assessment reported ?	Yes			
9	Sample size appropriate?	Yes			
10	Analytic methods described/justified and appropriate?		Partial		
11	Some estimate of variance is reported for the main results?				
12	Controlled for confounding?			No	
13	Results reported in sufficient detail?	Yes			
14	Conclusions supported by the results?	Yes			
Additional information available in the article?					
A	Effects of mixtures (i.e., effects that are not specific to only one chemical)	Yes			
B	Effects of low doses over long periods of time	Yes			
C	Long- and short-range dispersion and deposition			No	
				Total sum	**14**
				Total possible sum	**20**
				Summary score	**0.7**

Scoring

Item score is based on the degree that which the specific criteria are met ("yes" = 2, "partial" = 1, "no" = 0)

Items not applicable to a particular study design are marked "n/a" and are excluded from the scoring

Calculation of summary score:

Total sum = (number of "yes" * 2) + (number of "partials" *1)

Total possible sum = 28 - (number of "n/a" * 2)

Summary score: total sum / total possible sum

1. Kmet LM, Lee RC, and Cook LS. 2004. Standard quality assessment criteria for evaluating primary research papers from a variety of fields. Available at: https://www.ihe.ca/publications/standard-quality-assessment-criteria-for-evaluating-primary-research-papers-from-a-variety-of-fields

Title: Hazardous Air Pollutants (HAPs) Emission Estimates and Inhalation Human Health Risk Assessment for U.S. Coal-Fired Electric Generating Units: 2017 Base Year Post-MATS Evaluation
Author: Electric Power Research Institute (EPRI); P. Chu and E. Knipping

Checklist for Assessing the Quality of Quantitative Studies[1]

	Criteria	Yes (2)	Partial (1)	No (0)	N/A
1	Question / objective sufficiently described?	Yes			
2	Study design evident and appropriate ?	Yes			
3	Method of subject/comparison group selection or source of information/input variables described and appropriate ?	Yes			
4	Subject (and comparison group, if applicable) characteristics sufficiently described?				N/A
5	If random allocation was possible, was it described?				N/A
6	If blinding of investigators/subjects was possible was it reported?				N/A
7	Exposure measure(s) well defined and robust to meaasement /misclassification bias? Means of assessment reported?	Yes			
8	Outcome well defined and robust to measurement/misclassification bias? Means of assessment reported ?	Yes			
9	Sample size appropriate?				N/A
10	Analytic methods described/justified and appropriate?	Yes			
11	Some estimate of variance is reported for the main results?	Yes			
12	Controlled for confounding?			No	
13	Results reported in sufficient detail?	Yes			
14	Conclusions supported by the results?	Yes			
Additional information available in the article?					
A	Effects of mixtures (i.e., effects that are not specific to only one chemical)	Yes			
B	Effects of low doses over long periods of time	Yes			
C	Long- and short-range dispersion and deposition			No	
				Total sum	**18**
				Total possible sum	**20**
				Summary score	**0.9**

Scoring
Item score is based on the degree that which the specific criteria are met ("yes" = 2, "partial" = 1, "no" = 0
Items not applicable to a particular study design are marked "n/a" and are excluded from the scoring
Calculation of summary score:
Total sum = (number of "yes" * 2) + (number of "partials" *1)
Total possible sum = 28 - (number of "n/a" * 2)
Summary score: total sum / total possible sum

1. Kmet LM, Lee RC, and Cook LS. 2004. Standard quality assessment criteria for evaluating primary research papers from a variety of fields. Available at: https://www.ihe.ca/publications/standard-quality-assessment-criteria-for-evaluating-primary-research-papers-from-a-variety-of-fields

Title: Tracking and Evaluation of Benefits and Impacts of Greenhouse Gas Limits in Disadvantaged Communities: Initial Report

Author: Office of Environmenta Health Hazard Assessment, California Environmental Proection Agency

Checklist for Assessing the Quality of Quantitative Studies[1]

	Criteria	Yes (2)	Partial (1)	No (0)	N/A
1	Question / objective sufficiently described?	Yes			
2	Study design evident and appropriate ?	Yes			
3	Method of subject/comparison group selection or source of information/input variables described and appropriate ?	Yes			
4	Subject (and comparison group, if applicable) characteristics sufficiently described?	Yes			
5	If random allocation was possible, was it described?				N/A
6	If blinding of investigators/subjects was possible was it reported?				N/A
7	Exposure measure(s) well defined and robust to meaesement /misclassification bias? Means of assessment reported?				N/A
8	Outcome well defined and robust to measurement/misclassification bias? Means of assessment reported ?		Partial		
9	Sample size appropriate?	Yes			
10	Analytic methods described/justified and appropriate?	Yes			
11	Some estimate of variance is reported for the main results?		Partial		
12	Controlled for confounding?			No	
13	Results reported in sufficient detail?	Yes			
14	Conclusions supported by the results?	Yes			
Additional information available in the article?					
A	Effects of mixtures (i.e., effects that are not specific to only one chemical)	Yes			
B	Effects of low doses over long periods of time			No	
C	Long- and short-range dispersion and deposition			No	
				Total sum	**16**
				Total possible sum	**22**
				Summary score	**0.7**

Scoring

Item score is based on the degree that which the specific criteria are met ("yes" = 2, "partial" = 1, "no" = 0)

Items not applicable to a particular study design are marked "n/a" and are excluded from the scoring

Calculation of summary score:

Total sum = (number of "yes" * 2) + (number of "partials" *1)

Total possible sum = 28 - (number of "n/a" * 2)

Summary score: total sum / total possible sum

1. Kmet LM, Lee RC, and Cook LS. 2004. Standard quality assessment criteria for evaluating primary research papers from a variety of fields. Available at: https://www.ihe.ca/publications/standard-quality-assessment-criteria-for-evaluating-primary-research-papers-from-a-variety-of-fields

Title: Asthma and Air Pollution in Baltimore City
Author: Environmental Integrity Project

Checklist for Assessing the Quality of Quantitative Studies[1]

Criteria		Yes (2)	Partial (1)	No (0)	N/A
1	Question / objective sufficiently described?	Yes			
2	Study design evident and appropriate ?			No	
3	Method of subject/comparison group selection or source of information/input variables described and appropriate ?	Yes			
4	Subject (and comparison group, if applicable) characteristics sufficiently described?		Partial		
5	If random allocation was possible, was it described?				N/A
6	If blinding of investigators/subjects was possible was it reported?				N/A
7	Exposure measure(s) well defined and robust to measement /misclassification bias? Means of assessment reported?		Partial		
8	Outcome well defined and robust to measurement/misclassification bias? Means of assessment reported ?	Yes			
9	Sample size appropriate?	Yes			
10	Analytic methods described/justified and appropriate?				N/A
11	Some estimate of variance is reported for the main results?				N/A
12	Controlled for confounding?			No	
13	Results reported in sufficient detail?		Partial		
14	Conclusions supported by the results?	Yes			
Additional information available in the article?					
A	Effects of mixtures (i.e., effects that are not specific to only one chemical)	Yes			
B	Effects of low doses over long periods of time			No	
C	Long- and short-range dispersion and deposition			No	
				Total sum	**10**
				Total possible sum	**20**
				Summary score	**0.5**

Scoring

Item score is based on the degree that which the specific criteria are met ("yes" = 2, "partial" = 1, "no" = 0)

Items not applicable to a particular study design are marked "n/a" and are excluded from the scoring

Calculation of summary score:

Total sum = (number of "yes" * 2) + (number of "partials" *1)

Total possible sum = 28 - (number of "n/a" * 2)

Summary score: total sum / total possible sum

1. Kmet LM, Lee RC, and Cook LS. 2004. Standard quality assessment criteria for evaluating primary research papers from a variety of fields. Available at: https://www.ihe.ca/publications/standard-quality-assessment-criteria-for-evaluating-primary-research-papers-from-a-variety-of-fields

Title: Human Cost of Coal Power
Author: Greenpeace

Checklist for Assessing the Quality of Quantitative Studies[1]

Criteria		Yes (2)	Partial (1)	No (0)	N/A
1	Question / objective sufficiently described?	Yes			
2	Study design evident and appropriate ?	Yes			
3	Method of subject/comparison group selection or source of information/input variables described and appropriate ?	Yes			
4	Subject (and comparison group, if applicable) characteristics sufficiently described?				N/A
5	If random allocation was possible, was it described?				N/A
6	If blinding of investigators/subjects was possible was it reported?				N/A
7	Exposure measure(s) well defined and robust to measement /misclassification bias? Means of assessment reported?				N/A
8	Outcome well defined and robust to measurement/misclassification bias? Means of assessment reported ?		Partial		
9	Sample size appropriate?	Yes			
10	Analytic methods described/justified and appropriate?	Yes			
11	Some estimate of variance is reported for the main results?		Partial		
12	Controlled for confounding?	Yes			
13	Results reported in sufficient detail?		Partial		
14	Conclusions supported by the results?	Yes			
Additional information available in the article?					
A	Effects of mixtures (i.e., effects that are not specific to only one chemical)			No	
B	Effects of low doses over long periods of time			No	
C	Long- and short-range dispersion and deposition			No	
				Total sum	**14**
				Total possible sum	**20**
				Summary score	**0.7**

Scoring

Item score is based on the degree that which the specific criteria are met ("yes" = 2, "partial" = 1, "no" = 0)

Items not applicable to a particular study design are marked "n/a" and are excluded from the scoring

Calculation of summary score:

Total sum = (number of "yes" * 2) + (number of "partials" *1)

Total possible sum = 28 - (number of "n/a" * 2)

Summary score: total sum / total possible sum

1. Kmet LM, Lee RC, and Cook LS. 2004. Standard quality assessment criteria for evaluating primary research papers from a variety of fields. Available at: https://www.ihe.ca/publications/standard-quality-assessment-criteria-for-evaluating-primary-research-papers-from-a-variety-of-fields

Title: Gaseous Pollutants and Particulate Matter (PM) in Ambient Air and the Number of New Cases of Type 1 Diabetes in Children and Adolescents in the Pomeranian Voivodeship, Poland

Author: Michalska, Malgorzata; Zorena, Katarzyna; Waz, Piotr; Bartoszewicz, Maria; Brandt-Varma, Agnieszka; Slezak, Daniel; Robakowska, Marlena

Full Article? - Available free online.

Checklist for Assessing the Quality of Quantitative Studies[1]

Criteria		Yes (2)	Partial (1)	No (0)	N/A	Notes
1	Question / objective sufficiently described?	Yes				
2	Study design evident and appropriate ?	Yes				
3	Method of subject/comparison group selection or source of information/input variables described and appropriate ?	Yes				
4	Subject (and comparison group, if applicable) characteristics sufficiently described?	Yes				
5	If random allocation was possible, was it described?				N/A	
6	If blinding of investigators/subjects was possible was it reported?				N/A	
7	Exposure measure(s) well defined and robust to measement /misclassification bias? Means of assessment reported?	Yes				
8	Outcome well defined and robust to measurement/misclassification bias? Means of assessment reported ?	Yes				
9	Sample size appropriate?	Yes				
10	Analytic methods described/justified and appropriate?	Yes				
11	Some estimate of variance is reported for the main results?	Yes				
12	Controlled for confounding?			No		
13	Results reported in sufficient detail?	Yes				
14	Conclusions supported by the results?	Yes				
Additional information available in the article?						
A	Effects of mixtures (i.e., effects that are not specific to only one chemical)			No		
B	Effects of low doses over long periods of time		Yes			Exposure was chronic, however concentrations were moderate (i.e., PM above EU limits)
C	Long- and short-range dispersion and deposition			No		
				Total sum	**22**	
				Total possible sum	**24**	
				Summary score	**0.916666667**	

Scoring

Item score is based on the degree that which the specific criteria are met ("yes" = 2, "partial" = 1, "no" = 0)

Items not applicable to a particular study design are marked "n/a" and are excluded from the scoring

Calculation of summary score:

Total sum = (number of "yes" * 2) + (number of "partials" *1)

Total possible sum = 28 - (number of "n/a" * 2)

Summary score: total sum / total possible sum

1. Kmet LM, Lee RC, and Cook LS. 2004. Standard quality assessment criteria for evaluating primary research papers from a variety of fields. Available at: https://www.ihe.ca/publications/standard-quality-assessment-criteria-for-evaluating-primary-research-papers-from-a-variety-of-fields

Title: Air pollution and early deaths in the United States. Part I: Quantifyingthe impact of major sectors in 2005
Author: Fabio Caiazzo, Akshay Ashok, Ian A. Waitz, Steve H.L. Yim, Steven R.H. Barrett

Full Article? - Available free online.

Checklist for Assessing the Quality of Quantitative Studies[1]

	Criteria	Yes (2)	Partial (1)	No (0)	N/A	Notes
1	Question / objective sufficiently described?	Yes				
2	Study design evident and appropriate ?	Yes				
3	Method of subject/comparison group selection or source of information/input variables described and appropriate ?				N/A	
4	Subject (and comparison group, if applicable) characteristics sufficiently described?				N/A	
5	If random allocation was possible, was it described?				N/A	
6	If blinding of investigators/subjects was possible was it reported?				N/A	
7	Exposure measure(s) well defined and robust to measement /misclassification bias? Means of assessment reported?	Yes				
8	Outcome well defined and robust to measurement/misclassification bias? Means of assessment reported ?	Yes				
9	Sample size appropriate?	Yes				
10	Analytic methods described/justified and appropriate?	Yes				
11	Some estimate of variance is reported for the main results?	Yes				
12	Controlled for confounding?		Yes			
13	Results reported in sufficient detail?	Yes				
14	Conclusions supported by the results?	Yes				
Additional information available in the article?						
A	Effects of mixtures (i.e., effects that are not specific to only one chemical)			No		Study considered PM and ozone, but individually
B	Effects of low doses over long periods of time	Yes				
C	Long- and short-range dispersion and deposition		Yes			
				Total sum	**19**	
				Total possible sum	**20**	
				Summary score	**0.95**	

Scoring
Item score is based on the degree that which the specific criteria are met ("yes" = 2, "partial" = 1, "no" = 0)
Items not applicable to a particular study design are marked "n/a" and are excluded from the scoring
Calculation of summary score:
Total sum = (number of "yes" * 2) + (number of "partials" *1)
Total possible sum = 28 - (number of "n/a" * 2)
Summary score: total sum / total possible sum

1. Kmet LM, Lee RC, and Cook LS. 2004. Standard quality assessment criteria for evaluating primary research papers from a variety of fields. Available at: https://www.ihe.ca/publications/standard-quality-assessment-criteria-for-evaluating-primary-research-papers-from-a-variety-of-fields

Title: Sex differences in the association between exposure to indoor particulate matter and cognitive control among children (age 6–14 years) living near coal-fired power plants.
Author: Sears, Clara G.; Sears, Lonnie; Zierold, Kristina M.

Full Article? - Purchased

Checklist for Assessing the Quality of Quantitative Studies[1]

	Criteria	Yes (2)	Partial (1)	No (0)	N/A	Notes
1	Question / objective sufficiently described?	Yes				
2	Study design evident and appropriate ?	Yes				
3	Method of subject/comparison group selection or source of information/input variables described and appropriate ?	Yes				
4	Subject (and comparison group, if applicable) characteristics sufficiently described?	Yes				
5	If random allocation was possible, was it described?				N/A	
6	If blinding of investigators/subjects was possible was it reported?				N/A	
7	Exposure measure(s) well defined and robust to measement /misclassification bias? Means of assessment reported?	Yes				
8	Outcome well defined and robust to measurement/misclassification bias? Means of assessment reported ?	Yes				
9	Sample size appropriate?	Yes				
10	Analytic methods described/justified and appropriate?	Yes				
11	Some estimate of variance is reported for the main results?	Yes				
12	Controlled for confounding?		Yes			Study design included some control on limiting smoking during study, covariates
13	Results reported in sufficient detail?	Yes				
14	Conclusions supported by the results?	Yes				
Additional information available in the article?						
A	Effects of mixtures (i.e., effects that are not specific to only one chemical)			No		
B	Effects of low doses over long periods of time	Yes				
C	Long- and short-range dispersion and deposition			No		
				Total sum	**23**	
				Total possible sum	**24**	
				Summary score	**0.958333333**	

Scoring
Item score is based on the degree that which the specific criteria are met ("yes" = 2, "partial" = 1, "no" = 0)
Items not applicable to a particular study design are marked "n/a" and are excluded from the scoring
Calculation of summary score:
Total sum = (number of "yes" * 2) + (number of "partials" *1)
Total possible sum = 28 - (number of "n/a" * 2)
Summary score: total sum / total possible sum

1. Kmet LM, Lee RC, and Cook LS. 2004. Standard quality assessment criteria for evaluating primary research papers from a variety of fields. Available at: https://www.ihe.ca/publications/standard-quality-assessment-criteria-for-evaluating-primary-research-papers-from-a-variety-of-fields

Title: Association of PM2.5 with diabetes, asthma, and high blood pressure incidence in Canada: A spatiotemporal analysis of the impacts of the energy generation and fuel sales
Author: Requia, Weeberb J; Adams, Matthew D; Koutrakis, Petros

Full Article? - Purchased

Checklist for Assessing the Quality of Quantitative Studies[1]

	Criteria	Yes (2)	Partial (1)	No (0)	N/A
1	Question / objective sufficiently described?	Yes			
2	Study design evident and appropriate ?	Yes			
3	Method of subject/comparison group selection or source of information/input variables described and appropriate ?	Yes			
4	Subject (and comparison group, if applicable) characteristics sufficiently described?		Yes		
5	If random allocation was possible, was it described?				N/A
6	If blinding of investigators/subjects was possible was it reported?				N/A
7	Exposure measure(s) well defined and robust to measement /misclassification bias? Means of assessment reported?		Yes		
8	Outcome well defined and robust to measurement/misclassification bias? Means of assessment reported ?		Yes		
9	Sample size appropriate?	Yes			
10	Analytic methods described/justified and appropriate?	Yes			
11	Some estimate of variance is reported for the main results?	Yes			
12	Controlled for confounding?			No	
13	Results reported in sufficient detail?	Yes			
14	Conclusions supported by the results?	Yes			
Additional information available in the article?					
A	Effects of mixtures (i.e., effects that are not specific to only one chemical)			No	
B	Effects of low doses over long periods of time	Yes			
C	Long- and short-range dispersion and deposition			No	
				Total sum	**19**
				Total possible sum	**24**
				Summary score	**0.79166667**

Scoring
Item score is based on the degree that which the specific criteria are met ("yes" = 2, "partial" = 1, "no" = 0)
Items not applicable to a particular study design are marked "n/a" and are excluded from the scoring
Calculation of summary score:
Total sum = (number of "yes" * 2) + (number of "partials" *1)
Total possible sum = 28 - (number of "n/a" * 2)
Summary score: total sum / total possible sum

1. Kmet LM, Lee RC, and Cook LS. 2004. Standard quality assessment criteria for evaluating primary research papers from a variety of fields. Available at: https://www.ihe.ca/publications/standard-quality-assessment-criteria-for-evaluating-primary-research-papers-from-a-variety-of-fields

Title: The impact of power generation emissions on ambient PM.sub.2.5 pollution and human health in China and India
Author: Gao, Meng; Beig, Gufran; Song, Shaojie; Zhang, Hongliang; Hu, Jianlin; Ying, Qi; Liang, Fengchao; Liu, Yang; Wang, Haikun; Lu, Xiao; Zhu, Tong; Carmichael, Gregory R.; Nielsen, Chris P.; McElroy, Michael B.

Full Article? - Available free online.

Checklist for Assessing the Quality of Quantitative Studies[1]

	Criteria	Yes (2)	Partial (1)	No (0)	N/A
1	Question / objective sufficiently described?	Yes			
2	Study design evident and appropriate ?	Yes			
3	Method of subject/comparison group selection or source of information/input variables described and appropriate ?	Yes			
4	Subject (and comparison group, if applicable) characteristics sufficiently described?				N/A
5	If random allocation was possible, was it described?				N/A
6	If blinding of investigators/subjects was possible was it reported?				N/A
7	Exposure measure(s) well defined and robust to measement /misclassification bias? Means of assessment reported?	Yes			
8	Outcome well defined and robust to measurement/misclassification bias? Means of assessment reported ?	Yes			
9	Sample size appropriate?	Yes			
10	Analytic methods described/justified and appropriate?	Yes			
11	Some estimate of variance is reported for the main results?	Yes			
12	Controlled for confounding?		Yes		
13	Results reported in sufficient detail?	Yes			
14	Conclusions supported by the results?	Yes			
Additional information available in the article?					
A	Effects of mixtures (i.e., effects that are not specific to only one chemical)			No	
B	Effects of low doses over long periods of time			No	
C	Long- and short-range dispersion and deposition		Yes		
				Total sum	**21**
				Total possible sum	**22**
				Summary score	**0.954545455**

Scoring
Item score is based on the degree that which the specific criteria are met ("yes" = 2, "partial" = 1, "no" = 0)
Items not applicable to a particular study design are marked "n/a" and are excluded from the scoring
Calculation of summary score:
Total sum = (number of "yes" * 2) + (number of "partials" *1)
Total possible sum = 28 - (number of "n/a" * 2)
Summary score: total sum / total possible sum

1. Kmet LM, Lee RC, and Cook LS. 2004. Standard quality assessment criteria for evaluating primary research papers from a variety of fields. Available at: https://www.ihe.ca/publications/standard-quality-assessment-criteria-for-evaluating-primary-research-papers-from-a-variety-of-fields

Title: PM.sub.2.5-related health impacts of utilizing ammonia-hydrogen energy in Kanto Region, Japan
Author: Lu, Mengqian; Lin, Bin-Le; Inoue, Kazuya; Lei, Zhongfang; Zhang, Zhenya; Tsunemi, Kiyotaka

Full Article? - Purchased

Checklist for Assessing the Quality of Quantitative Studies[1]

	Criteria	Yes (2)	Partial (1)	No (0)	N/A
1	Question / objective sufficiently described?	Yes			
2	Study design evident and appropriate ?	Yes			
3	Method of subject/comparison group selection or source of information/input variables described and appropriate ?	Yes			
4	Subject (and comparison group, if applicable) characteristics sufficiently described?		Yes		
5	If random allocation was possible, was it described?				N/A
6	If blinding of investigators/subjects was possible was it reported?				N/A
7	Exposure measure(s) well defined and robust to measement /misclassification bias? Means of assessment reported?	Yes			
8	Outcome well defined and robust to measurement/misclassification bias? Means of assessment reported ?	Yes			
9	Sample size appropriate?	Yes			
10	Analytic methods described/justified and appropriate?	Yes			
11	Some estimate of variance is reported for the main results?			No	
12	Controlled for confounding?			No	
13	Results reported in sufficient detail?	Yes			
14	Conclusions supported by the results?	Yes			
Additional information available in the article?					
A	Effects of mixtures (i.e., effects that are not specific to only one chemical)			No	
B	Effects of low doses over long periods of time	Yes			
C	Long- and short-range dispersion and deposition		Yes		
				Total sum	**19**
				Total possible sum	**24**
				Summary score	**0.79166667**

Scoring
Item score is based on the degree that which the specific criteria are met ("yes" = 2, "partial" = 1, "no" = 0)
Items not applicable to a particular study design are marked "n/a" and are excluded from the scoring
Calculation of summary score:
Total sum = (number of "yes" * 2) + (number of "partials" *1)
Total possible sum = 28 - (number of "n/a" * 2)
Summary score: total sum / total possible sum

1. Kmet LM, Lee RC, and Cook LS. 2004. Standard quality assessment criteria for evaluating primary research papers from a variety of fields. Available at: https://www.ihe.ca/publications/standard-quality-assessment-criteria-for-evaluating-primary-research-papers-from-a-variety-of-fields

Title: Gene expression profiling of human bronchial epithelial cells exposed to fine particulate matter (PM2.5) from biomass combustion.
Author: Popadić, Désirée; Heßelbach, Katharina; Richter-Brockmann, Sigrid; Kim, Gwang-Jin; Flemming, Stephan; Schmidt-Heck, Wolfgang; Häupl, Thomas; Bonin, Marc; Dornhof, Regina; Achten, Christine; Günther, Stefan; Humar, Matjaz; Merfort, Irmgard

Full Article? - Purchased

Checklist for Assessing the Quality of Quantitative Studies[1]

	Criteria	Yes (2)	Partial (1)	No (0)	N/A	Notes
1	Question / objective sufficiently described?	Yes				
2	Study design evident and appropriate ?	Yes				
3	Method of subject/comparison group selection or source of information/input variables described and appropriate ?	Yes				
4	Subject (and comparison group, if applicable) characteristics sufficiently described?				N/A	
5	If random allocation was possible, was it described?				N/A	
6	If blinding of investigators/subjects was possible was it reported?				N/A	
7	Exposure measure(s) well defined and robust to measement /misclassification bias? Means of assessment reported?			No		Study refers to an outside report
8	Outcome well defined and robust to measurement/misclassification bias? Means of assessment reported ?	Yes				
9	Sample size appropriate?				N/A	
10	Analytic methods described/justified and appropriate?		Yes			Study refers to an outside report, not all analytical methods fully described in text
11	Some estimate of variance is reported for the main results?		Yes			
12	Controlled for confounding?		Yes			
13	Results reported in sufficient detail?	Yes				
14	Conclusions supported by the results?	Yes				
Additional information available in the article?						
A	Effects of mixtures (i.e., effects that are not specific to only one chemical)			No		
B	Effects of low doses over long periods of time		Yes			Study aimed to evaluate chronic effects; exposure duration of 5 weeks
C	Long- and short-range dispersion and deposition			No		
				Total sum	**15**	
				Total possible sum	**20**	
				Summary score	**0.75**	

Scoring
Item score is based on the degree that which the specific criteria are met ("yes" = 2, "partial" = 1, "no" = 0)
Items not applicable to a particular study design are marked "n/a" and are excluded from the scoring
Calculation of summary score:
Total sum = (number of "yes" * 2) + (number of "partials" *1)
Total possible sum = 28 - (number of "n/a" * 2)
Summary score: total sum / total possible sum

1. Kmet LM, Lee RC, and Cook LS. 2004. Standard quality assessment criteria for evaluating primary research papers from a variety of fields. Available at: https://www.ihe.ca/publications/standard-quality-assessment-criteria-for-evaluating-primary-research-papers-from-a-variety-of-fields

Title: Linking sources to early effects by profiling urine metabolome of residents living near oil refineries and coal-fired power plants
Author: Chen, Chi-Hsin Sally; Yuan, Tzu-Hsuen; Shie, Ruei-Hao; Wu, Kuen-Yuh; Chan, Chang-Chuan

Full Article? - Purchased

Checklist for Assessing the Quality of Quantitative Studies[1]

	Criteria	Yes (2)	Partial (1)	No (0)	N/A	Notes
1	Question / objective sufficiently described?	Yes				
2	Study design evident and appropriate ?	Yes				
3	Method of subject/comparison group selection or source of information/input variables described and appropriate ?	Yes				
4	Subject (and comparison group, if applicable) characteristics sufficiently described?	Yes				
5	If random allocation was possible, was it described?		Yes			Subjects within each group were selected randomly from larger total potential subject group
6	If blinding of investigators/subjects was possible was it reported?				N/A	
7	Exposure measure(s) well defined and robust to meausement /misclassification bias? Means of assessment reported?	Yes				
8	Outcome well defined and robust to measurement/misclassification bias? Means of assessment reported ?	Yes				
9	Sample size appropriate?	Yes				
10	Analytic methods described/justified and appropriate?	Yes				
11	Some estimate of variance is reported for the main results?	Yes				
12	Controlled for confounding?		Yes			Background including smoking, drinking, considered
13	Results reported in sufficient detail?	Yes				
14	Conclusions supported by the results?	Yes				
Additional information available in the article?						
A	Effects of mixtures (i.e., effects that are not specific to only one chemical)			No		
B	Effects of low doses over long periods of time			No		
C	Long- and short-range dispersion and deposition	Yes				Study compared low and high exposures based on distance from source emissions
				Total sum	**24**	
				Total possible sum	**26**	
				Summary score	**0.92307692**	

Scoring
Item score is based on the degree that which the specific criteria are met ("yes" = 2, "partial" = 1, "no" = 0)
Items not applicable to a particular study design are marked "n/a" and are excluded from the scoring
Calculation of summary score:
Total sum = (number of "yes" * 2) + (number of "partials" *1)
Total possible sum = 28 - (number of "n/a" * 2)
Summary score: total sum / total possible sum

1. Kmet LM, Lee RC, and Cook LS. 2004. Standard quality assessment criteria for evaluating primary research papers from a variety of fields. Available at: https://www.ihe.ca/publications/standard-quality-assessment-criteria-for-evaluating-primary-research-papers-from-a-variety-of-fields

Title: Bird species richness and densities in relation to sulphur dioxide gradients and environmental variables.
Author: Muyemeki, Luckson; Burger, Roelof; Piketh, Stuart J; Evans, Steven W

Full Article? - Purchased

Checklist for Assessing the Quality of Quantitative Studies[1]

	Criteria	Yes (2)	Partial (1)	No (0)	N/A
1	Question / objective sufficiently described?	Yes			
2	Study design evident and appropriate ?	Yes			
3	Method of subject/comparison group selection or source of information/input variables described and appropriate ?				N/A
4	Subject (and comparison group, if applicable) characteristics sufficiently described?				N/A
5	If random allocation was possible, was it described?		Yes		
6	If blinding of investigators/subjects was possible was it reported?				N/A
7	Exposure measure(s) well defined and robust to measement /misclassification bias? Means of assessment reported?		Yes		
8	Outcome well defined and robust to measurement/misclassification bias? Means of assessment reported ?		Yes		
9	Sample size appropriate?	Yes			
10	Analytic methods described/justified and appropriate?	Yes			
11	Some estimate of variance is reported for the main results?	Yes			
12	Controlled for confounding?			No	
13	Results reported in sufficient detail?		Yes		
14	Conclusions supported by the results?		Yes		
Additional information available in the article?					
A	Effects of mixtures (i.e., effects that are not specific to only one chemical)			No	
B	Effects of low doses over long periods of time			No	
C	Long- and short-range dispersion and deposition		Yes		
				Total sum	**15**
				Total possible sum	**22**
				Summary score	**0.681818182**

Scoring
Item score is based on the degree that which the specific criteria are met ("yes" = 2, "partial" = 1, "no" = 0)
Items not applicable to a particular study design are marked "n/a" and are excluded from the scoring
Calculation of summary score:
 Total sum = (number of "yes" * 2) + (number of "partials" *1)
 Total possible sum = 28 - (number of "n/a" * 2)
 Summary score: total sum / total possible sum

1. Kmet LM, Lee RC, and Cook LS. 2004. Standard quality assessment criteria for evaluating primary research papers from a variety of fields. Available at: https://www.ihe.ca/publications/standard-quality-assessment-criteria-for-evaluating-primary-research-papers-from-a-variety-of-fields

Title: Contribution of nitrogen oxide and sulfur dioxide exposure from power plant emissions on respiratory symptom and disease prevalence.
Author: Amster, Eric D.; Haim, Maayan; Dubnov, Jonathan; Broday, David M.

Full Article? - Purchased

Checklist for Assessing the Quality of Quantitative Studies[1]

	Criteria	Yes (2)	Partial (1)	No (0)	N/A	Notes
1	Question / objective sufficiently described?	Yes				
2	Study design evident and appropriate ?	Yes				
3	Method of subject/comparison group selection or source of information/input variables described and appropriate ?	Yes				
4	Subject (and comparison group, if applicable) characteristics sufficiently described?	Yes				
5	If random allocation was possible, was it described?		Yes			Subjects within each group were selected randomly from larger total potential subject group
6	If blinding of investigators/subjects was possible was it reported?				N/A	
7	Exposure measure(s) well defined and robust to measement /misclassification bias? Means of assessment reported?	Yes				
8	Outcome well defined and robust to measurement/misclassification bias? Means of assessment reported ?	Yes				
9	Sample size appropriate?	Yes				
10	Analytic methods described/justified and appropriate?		Yes			
11	Some estimate of variance is reported for the main results?	Yes				
12	Controlled for confounding?		Yes			Background including smoking, drinking, considered
13	Results reported in sufficient detail?	Yes				
14	Conclusions supported by the results?	Yes				
Additional information available in the article?						
A	Effects of mixtures (i.e., effects that are not specific to only one chemical)			No		
B	Effects of low doses over long periods of time	Yes				
C	Long- and short-range dispersion and deposition		Yes			
				Total sum	**23**	
				Total possible sum	**26**	
				Summary score	**0.88461538**	

Scoring
Item score is based on the degree that which the specific criteria are met ("yes" = 2, "partial" = 1, "no" = 0)
Items not applicable to a particular study design are marked "n/a" and are excluded from the scoring
Calculation of summary score:
Total sum = (number of "yes" * 2) + (number of "partials" *1)
Total possible sum = 28 - (number of "n/a" * 2)
Summary score: total sum / total possible sum

1. Kmet LM, Lee RC, and Cook LS. 2004. Standard quality assessment criteria for evaluating primary research papers from a variety of fields. Available at: https://www.ihe.ca/publications/standard-quality-assessment-criteria-for-evaluating-primary-research-papers-from-a-variety-of-fields

Title: Estimates of community exposure and health risk to sulfur dioxide from power plant emissions using short-term mobile and stationary ambient air monitoring
Author: Shepherd, Mark A.; Haynatzki, Gleb; Rautiainen, Risto; Achutan, Chandran

Full Article? - Available free online.

Checklist for Assessing the Quality of Quantitative Studies[1]

	Criteria	Yes (2)	Partial (1)	No (0)	N/A
1	Question / objective sufficiently described?	Yes			
2	Study design evident and appropriate ?	Yes			
3	Method of subject/comparison group selection or source of information/input variables described and appropriate ?				NA
4	Subject (and comparison group, if applicable) characteristics sufficiently described?				N/A
5	If random allocation was possible, was it described?				N/A
6	If blinding of investigators/subjects was possible was it reported?				N/A
7	Exposure measure(s) well defined and robust to measement /misclassification bias? Means of assessment reported?	Yes			
8	Outcome well defined and robust to measurement/misclassification bias? Means of assessment reported ?	Yes			
9	Sample size appropriate?		Yes		
10	Analytic methods described/justified and appropriate?	Yes			
11	Some estimate of variance is reported for the main results?		Yes		
12	Controlled for confounding?			No	
13	Results reported in sufficient detail?	Yes			
14	Conclusions supported by the results?	Yes			
Additional information available in the article?					
A	Effects of mixtures (i.e., effects that are not specific to only one chemical)			No	
B	Effects of low doses over long periods of time			No	
C	Long- and short-range dispersion and deposition	Yes			
				Total sum	**16**
				Total possible sum	**22**
				Summary score	**0.72727273**

Scoring
Item score is based on the degree that which the specific criteria are met ("yes" = 2, "partial" = 1, "no" = 0)
Items not applicable to a particular study design are marked "n/a" and are excluded from the scoring
Calculation of summary score:
Total sum = (number of "yes" * 2) + (number of "partials" *1)
Total possible sum = 28 - (number of "n/a" * 2)
Summary score: total sum / total possible sum

1. Kmet LM, Lee RC, and Cook LS. 2004. Standard quality assessment criteria for evaluating primary research papers from a variety of fields. Available at: https://www.ihe.ca/publications/standard-quality-assessment-criteria-for-evaluating-primary-research-papers-from-a-variety-of-fields

Title: Health Risk Assessment of Nitrogen Dioxide and Sulfur Dioxide Exposure from a New Developing Coal Power Plant in Thailand.
Author: Thongthammachart, Tin; Pimkotr, Krittiya; Jinsart, Wanida

Full Article? - Available free online.

Checklist for Assessing the Quality of Quantitative Studies[1]

	Criteria	Yes (2)	Partial (1)	No (0)	N/A	Notes
1	Question / objective sufficiently described?	Yes				
2	Study design evident and appropriate ?		Yes			
3	Method of subject/comparison group selection or source of information/input variables described and appropriate ?		Yes			
4	Subject (and comparison group, if applicable) characteristics sufficiently described?		Yes			
5	If random allocation was possible, was it described?				N/A	
6	If blinding of investigators/subjects was possible was it reported?				N/A	
7	Exposure measure(s) well defined and robust to measement /misclassification bias? Means of assessment reported?	Yes				
8	Outcome well defined and robust to measurement/misclassification bias? Means of assessment reported ?	Yes				
9	Sample size appropriate?		Yes			
10	Analytic methods described/justified and appropriate?	Yes				
11	Some estimate of variance is reported for the main results?		Yes			
12	Controlled for confounding?			No		
13	Results reported in sufficient detail?	Yes				
14	Conclusions supported by the results?	Yes				
Additional information available in the article?						
A	Effects of mixtures (i.e., effects that are not specific to only one chemical)			No		Study looked at two parameters, but did not considered synergistic/additive effects
B	Effects of low doses over long periods of time			No		
C	Long- and short-range dispersion and deposition		Yes			
					Total sum	**17**
					Total possible sum	**24**
					Summary score	**0.708333333**

Scoring
Item score is based on the degree that which the specific criteria are met ("yes" = 2, "partial" = 1, "no" = 0)
Items not applicable to a particular study design are marked "n/a" and are excluded from the scoring
Calculation of summary score:
Total sum = (number of "yes" * 2) + (number of "partials" *1)
Total possible sum = 28 - (number of "n/a" * 2)
Summary score: total sum / total possible sum

1. Kmet LM, Lee RC, and Cook LS. 2004. Standard quality assessment criteria for evaluating primary research papers from a variety of fields. Available at: https://www.ihe.ca/publications/standard-quality-assessment-criteria-for-evaluating-primary-research-papers-from-a-variety-of-fields

Title: The value of health damage due to sulphur dioxide emissions from coal-fired electricity generation in NSW and implications for pollution licences.
Author: Ewald, Ben

Full Article? - Available free online.

Checklist for Assessing the Quality of Quantitative Studies[1]

	Criteria	Yes (2)	Partial (1)	No (0)	N/A
1	Question / objective sufficiently described?		Yes		
2	Study design evident and appropriate ?		Yes		
3	Method of subject/comparison group selection or source of information/input variables described and appropriate ?		Yes		
4	Subject (and comparison group, if applicable) characteristics sufficiently described?				N/A
5	If random allocation was possible, was it described?				N/A
6	If blinding of investigators/subjects was possible was it reported?				N/A
7	Exposure measure(s) well defined and robust to measement /misclassification bias? Means of assessment reported?	Yes			
8	Outcome well defined and robust to measurement/misclassification bias? Means of assessment reported ?		Yes		
9	Sample size appropriate?	Yes			
10	Analytic methods described/justified and appropriate?		Yes		
11	Some estimate of variance is reported for the main results?	Yes			
12	Controlled for confounding?			No	
13	Results reported in sufficient detail?	Yes			
14	Conclusions supported by the results?		Yes		
Additional information available in the article?					
A	Effects of mixtures (i.e., effects that are not specific to only one chemical)			No	
B	Effects of low doses over long periods of time			No	
C	Long- and short-range dispersion and deposition			No	
				Total sum	**13**
				Total possible sum	**22**
				Summary score	**0.590909091**

Scoring
Item score is based on the degree that which the specific criteria are met ("yes" = 2, "partial" = 1, "no" = 0)
Items not applicable to a particular study design are marked "n/a" and are excluded from the scoring
Calculation of summary score:
  Total sum = (number of "yes" * 2) + (number of "partials" *1)
  Total possible sum = 28 - (number of "n/a" * 2)
  Summary score: total sum / total possible sum

1. Kmet LM, Lee RC, and Cook LS. 2004. Standard quality assessment criteria for evaluating primary research papers from a variety of fields. Available at: https://www.ihe.ca/publications/standard-quality-assessment-criteria-for-evaluating-primary-research-papers-from-a-variety-of-fields

Title: External costs of atmospheric lead emissions from a waste-to-energy plant: A follow-up assessment of indirect exposure via topsoil ingestion
Author: Pizzol, Massimo; Møller, Flemming; Thomsen, Marianne

Full Article? - Purchased

Checklist for Assessing the Quality of Quantitative Studies[1]

Criteria		Yes (2)	Partial (1)	No (0)	N/A	Notes
1	Question / objective sufficiently described?	Yes				
2	Study design evident and appropriate ?	Yes				
3	Method of subject/comparison group selection or source of information/input variables described and appropriate ?	Yes				
4	Subject (and comparison group, if applicable) characteristics sufficiently described?		Yes			Limited details provided
5	If random allocation was possible, was it described?					Unknown
6	If blinding of investigators/subjects was possible was it reported?				N/A	
7	Exposure measure(s) well defined and robust to measement /misclassification bias? Means of assessment reported?		Yes			Yes for lead exposure, no for IQ calculations
8	Outcome well defined and robust to measurement/misclassification bias? Means of assessment reported ?		Yes			
9	Sample size appropriate?					Unknown
10	Analytic methods described/justified and appropriate?	Yes				
11	Some estimate of variance is reported for the main results?	Yes				
12	Controlled for confounding?			No		
13	Results reported in sufficient detail?			No		
14	Conclusions supported by the results?					Unknown
Additional information available in the article?						
A	Effects of mixtures (i.e., effects that are not specific to only one chemical)			No		
B	Effects of low doses over long periods of time	Yes				
C	Long- and short-range dispersion and deposition	Yes				
				Total sum	**13**	
				Total possible sum	**26**	
				Summary score	**0.5**	

Scoring
Item score is based on the degree that which the specific criteria are met ("yes" = 2, "partial" = 1, "no" = 0)
Items not applicable to a particular study design are marked "n/a" and are excluded from the scoring
Calculation of summary score:
Total sum = (number of "yes" * 2) + (number of "partials" *1)
Total possible sum = 28 - (number of "n/a" * 2)
Summary score: total sum / total possible sum

1. Kmet LM, Lee RC, and Cook LS. 2004. Standard quality assessment criteria for evaluating primary research papers from a variety of fields. Available at: https://www.ihe.ca/publications/standard-quality-assessment-criteria-for-evaluating-primary-research-papers-from-a-variety-of-fields

Title: Comparative study of PM10-bound heavy metals and PAHs during six years in a Chinese megacity: Compositions, sources, and source-specific risks
Author: Xue, Qianqian; Jiang, Zhuo; Wang, Xiang; Song, Danlin; Huang, Fengxia; Tian, Yingze; Huang-fu, Yanqi; Feng, Yinchang

Full Article? - Purchased

Checklist for Assessing the Quality of Quantitative Studies[1]

	Criteria	Yes (2)	Partial (1)	No (0)	N/A	Notes
1	Question / objective sufficiently described?	Yes				
2	Study design evident and appropriate ?	Yes				
3	Method of subject/comparison group selection or source of information/input variables described and appropriate ?				N/A	No specific group, generic exposure used in risk calculations
4	Subject (and comparison group, if applicable) characteristics sufficiently described?	Yes				Equation inputs in appendix
5	If random allocation was possible, was it described?				N/A	
6	If blinding of investigators/subjects was possible was it reported?				N/A	
7	Exposure measure(s) well defined and robust to meassement /misclassification bias? Means of assessment reported?		Yes			It is noted that extended details of the study are provided in appendices rather than the main text. Still lacking some information (i.e., number of samples)
8	Outcome well defined and robust to measurement/misclassification bias? Means of assessment reported ?	Yes				
9	Sample size appropriate?				N/A	
10	Analytic methods described/justified and appropriate?	Yes				It is noted that extended details of the study are provided in appendices rather than the main text
11	Some estimate of variance is reported for the main results?		Yes			
12	Controlled for confounding?			No		
13	Results reported in sufficient detail?		Yes			
14	Conclusions supported by the results?	Yes				
Additional information available in the article?						
A	Effects of mixtures (i.e., effects that are not specific to only one chemical)	Yes				Risks of parameter groups (metals, PAHs) were summed
B	Effects of low doses over long periods of time		Yes			Long exposure period, but assessment did not focus on chronic effects (just overall risk)
C	Long- and short-range dispersion and deposition			No		
				Total sum	**15**	
				Total possible sum	**20**	
				Summary score	**0.75**	

Scoring
Item score is based on the degree that which the specific criteria are met ("yes" = 2, "partial" = 1, "no" = 0)
Items not applicable to a particular study design are marked "n/a" and are excluded from the scoring
Calculation of summary score:
Total sum = (number of "yes" * 2) + (number of "partials" *1)
Total possible sum = 28 - (number of "n/a" * 2)
Summary score: total sum / total possible sum

1. Kmet LM, Lee RC, and Cook LS. 2004. Standard quality assessment criteria for evaluating primary research papers from a variety of fields. Available at: https://www.ihe.ca/publications/standard-quality-assessment-criteria-for-evaluating-primary-research-papers-from-a-variety-of-fields

Title: Characteristics, sources and health risks of toxic species (PCDD/Fs, PAHs and heavy metals) in PM2.5 during fall and winter in an industrial area
Author: Bi, Chenglu; Chen, Yantong; Zhao, Zhuzi; Li, Qing; Zhou, Quanfa; Ye, Zhaolian; Ge, Xinlei

Full Article? - Purchased

Checklist for Assessing the Quality of Quantitative Studies[1]

	Criteria	Yes (2)	Partial (1)	No (0)	N/A	Notes
1	Question / objective sufficiently described?	Yes				
2	Study design evident and appropriate ?	Yes				
3	Method of subject/comparison group selection or source of information/input variables described and appropriate ?				N/A	No specific group, generic exposure used in risk calculations
4	Subject (and comparison group, if applicable) characteristics sufficiently described?	Yes				
5	If random allocation was possible, was it described?				N/A	
6	If blinding of investigators/subjects was possible was it reported?				N/A	
7	Exposure measure(s) well defined and robust to measement /misclassification bias? Means of assessment reported?	Yes				
8	Outcome well defined and robust to measurement/misclassification bias? Means of assessment reported ?	Yes				
9	Sample size appropriate?				N/A	
10	Analytic methods described/justified and appropriate?	Yes				
11	Some estimate of variance is reported for the main results?			No		
12	Controlled for confounding?			No		
13	Results reported in sufficient detail?	Yes				
14	Conclusions supported by the results?	Yes				
Additional information available in the article?						
A	Effects of mixtures (i.e., effects that are not specific to only one chemical)	Yes				PAH concentrations were summed and evaluated
B	Effects of low doses over long periods of time			No		
C	Long- and short-range dispersion and deposition			No		
				Total sum	**16**	
				Total possible sum	**20**	
				Summary score	**0.8**	

Scoring
Item score is based on the degree that which the specific criteria are met ("yes" = 2, "partial" = 1, "no" = 0)
Items not applicable to a particular study design are marked "n/a" and are excluded from the scoring
Calculation of summary score:
    Total sum = (number of "yes" * 2) + (number of "partials" *1)
    Total possible sum = 28 - (number of "n/a" * 2)
    Summary score: total sum / total possible sum

1. Kmet LM, Lee RC, and Cook LS. 2004. Standard quality assessment criteria for evaluating primary research papers from a variety of fields. Available at: https://www.ihe.ca/publications/standard-quality-assessment-criteria-for-evaluating-primary-research-papers-from-a-variety-of-fields

Title: Seasonal concentration distribution of PM1.0 and PM2.5 and a risk assessment of bound trace metals in Harbin, China: Effect of the species distribution of heavy metals and heat supply.
Author: Wang, Kun; Wang, Weiye; Li, Lili; Li, Jianju; Wei, Liangliang; Chi, Wanqiu; Hong, Lijing; Zhao, Qingliang; Jiang, Junqiu

Full Article? - Available free online.

Checklist for Assessing the Quality of Quantitative Studies[1]

	Criteria	Yes (2)	Partial (1)	No (0)	N/A	Notes
1	Question / objective sufficiently described?	Yes				
2	Study design evident and appropriate ?	Yes				
3	Method of subject/comparison group selection or source of information/input variables described and appropriate ?	Yes				
4	Subject (and comparison group, if applicable) characteristics sufficiently described?	Yes				
5	If random allocation was possible, was it described?				N/A	
6	If blinding of investigators/subjects was possible was it reported?				N/A	
7	Exposure measure(s) well defined and robust to measement /misclassification bias? Means of assessment reported?	Yes				
8	Outcome well defined and robust to measurement/misclassification bias? Means of assessment reported ?	Yes				
9	Sample size appropriate?				N/A	
10	Analytic methods described/justified and appropriate?	Yes				
11	Some estimate of variance is reported for the main results?			No		
12	Controlled for confounding?			No		
13	Results reported in sufficient detail?	Yes				
14	Conclusions supported by the results?	Yes				
Additional information available in the article?						
A	Effects of mixtures (i.e., effects that are not specific to only one chemical)		Yes			Deals with multiple parameters evaluated in isolation; risks were summed but was a numerical exercise, cumulative effects not discussed
B	Effects of low doses over long periods of time			No		
C	Long- and short-range dispersion and deposition			No		
				Total sum	**18**	
				Total possible sum	**22**	
				Summary score	**0.81818182**	

Scoring
Item score is based on the degree that which the specific criteria are met ("yes" = 2, "partial" = 1, "no" = 0)
Items not applicable to a particular study design are marked "n/a" and are excluded from the scoring
Calculation of summary score:
Total sum = (number of "yes" * 2) + (number of "partials" *1)
Total possible sum = 28 - (number of "n/a" * 2)
Summary score: total sum / total possible sum

1. Kmet LM, Lee RC, and Cook LS. 2004. Standard quality assessment criteria for evaluating primary research papers from a variety of fields. Available at: https://www.ihe.ca/publications/standard-quality-assessment-criteria-for-evaluating-primary-research-papers-from-a-variety-of-fields

Title: Urinary Heavy Metal levels of Residents in the Vicinity of a Petrochemical Complex in Taiwan
Author: Yuan T. H.; Pien W. H.; Chan C. C.

Full Article? - Available free online.

Checklist for Assessing the Quality of Quantitative Studies[1]

	Criteria	Yes (2)	Partial (1)	No (0)	N/A
1	Question / objective sufficiently described?	Yes			
2	Study design evident and appropriate ?	Yes			
3	Method of subject/comparison group selection or source of information/input variables described and appropriate ?	Yes			
4	Subject (and comparison group, if applicable) characteristics sufficiently described?	Yes			
5	If random allocation was possible, was it described?				N/A
6	If blinding of investigators/subjects was possible was it reported?				N/A
7	Exposure measure(s) well defined and robust to meaesement /misclassification bias? Means of assessment reported?	Yes			
8	Outcome well defined and robust to measurement/misclassification bias? Means of assessment reported ?	Yes			
9	Sample size appropriate?	Yes			
10	Analytic methods described/justified and appropriate?	Yes			
11	Some estimate of variance is reported for the main results?		Yes		
12	Controlled for confounding?	Yes			
13	Results reported in sufficient detail?		Yes		
14	Conclusions supported by the results?	Yes			
Additional information available in the article?					
A	Effects of mixtures (i.e., effects that are not specific to only one chemical)			No	
B	Effects of low doses over long periods of time		Yes		
C	Long- and short-range dispersion and deposition		Yes		
				Total sum	**22**
				Total possible sum	**24**
				Summary score	**0.91666667**

Scoring
Item score is based on the degree that which the specific criteria are met ("yes" = 2, "partial" = 1, "no" = 0)
Items not applicable to a particular study design are marked "n/a" and are excluded from the scoring
Calculation of summary score:
Total sum = (number of "yes" * 2) + (number of "partials" *1)
Total possible sum = 28 - (number of "n/a" * 2)
Summary score: total sum / total possible sum

1. Kmet LM, Lee RC, and Cook LS. 2004. Standard quality assessment criteria for evaluating primary research papers from a variety of fields. Available at: https://www.ihe.ca/publications/standard-quality-assessment-criteria-for-evaluating-primary-research-papers-from-a-variety-of-fields

Title: Study on the environmental effects of heavy metals in coal gangue and coal combustion by ReCiPe2016 for life cycle impact assessment
Author: PENG, Hao; WANG, Bao-feng; YANG, Feng-ling; CHENG, Fang-qin

Full Article? - Purchased

Checklist for Assessing the Quality of Quantitative Studies[1]

	Criteria	Yes (2)	Partial (1)	No (0)	N/A	Notes
1	Question / objective sufficiently described?	Yes				
2	Study design evident and appropriate ?		Yes			Software used is identified, but software is not explained
3	Method of subject/comparison group selection or source of information/input variables described and appropriate ?				N/A	
4	Subject (and comparison group, if applicable) characteristics sufficiently described?				N/A	
5	If random allocation was possible, was it described?				N/A	
6	If blinding of investigators/subjects was possible was it reported?				N/A	
7	Exposure measure(s) well defined and robust to measement /misclassification bias? Means of assessment reported?		Yes			Yes for emission exposure, no for application of software
8	Outcome well defined and robust to measurement/misclassification bias? Means of assessment reported ?		Yes			
9	Sample size appropriate?				N/A	
10	Analytic methods described/justified and appropriate?		Yes			Software used is identified, but software is not explained
11	Some estimate of variance is reported for the main results?		Yes			Yes for emission exposure, no for application of software
12	Controlled for confounding?				N/A	
13	Results reported in sufficient detail?			No		
14	Conclusions supported by the results?					Results not explained thoroughly
Additional information available in the article?						Unknown
A	Effects of mixtures (i.e., effects that are not specific to only one chemical)			No		
B	Effects of low doses over long periods of time			No		
C	Long- and short-range dispersion and deposition			No		
				Total sum	**7**	
				Total possible sum	**16**	
				Summary score	**0.4375**	

Scoring
Item score is based on the degree that which the specific criteria are met ("yes" = 2, "partial" = 1, "no" = 0)
Items not applicable to a particular study design are marked "n/a" and are excluded from the scoring
Calculation of summary score:
Total sum = (number of "yes" * 2) + (number of "partials" *1)
Total possible sum = 28 - (number of "n/a" * 2)
Summary score: total sum / total possible sum

1. Kmet LM, Lee RC, and Cook LS. 2004. Standard quality assessment criteria for evaluating primary research papers from a variety of fields. Available at: https://www.ihe.ca/publications/standard-quality-assessment-criteria-for-evaluating-primary-research-papers-from-a-variety-of-fields

Title: Sub-type source profiles of fine particles for fugitive dust and accumulative health risks of heavy metals: a case study in a fast-developing city of China
Author: Wu F; Kong S; Yan Q; Wang W; Liu H; Wu J; Zheng H; Zheng S; Cheng Y; Niu Z; Liu D; Qi S

Full Article? - Purchased

AFTER REVIEW OF FULL ARTICLE, IT CANNOT BE CONCLUDED THAT EMISSIONS FROM POWER PLANTS/ENERGY GENERATION ARE A SIGNIFICANT SOURCE OF EXPOSURE IN THE STUDY AND WILL NOT BE SUMMARIZED IN THE REPORT

Checklist for Assessing the Quality of Quantitative Studies[1]

	Criteria	Yes (2)	Partial (1)	No (0)	N/A	Notes
1	Question / objective sufficiently described?	Yes				
2	Study design evident and appropriate ?	Yes				
3	Method of subject/comparison group selection or source of information/input variables described and appropriate ?				N/A	No specific group, generic exposure used in risk calculations
4	Subject (and comparison group, if applicable) characteristics sufficiently described?	Yes				
5	If random allocation was possible, was it described?				N/A	
6	If blinding of investigators/subjects was possible was it reported?				N/A	
7	Exposure measure(s) well defined and robust to measement /misclassification bias? Means of assessment reported?	Yes				
8	Outcome well defined and robust to measurement/misclassification bias? Means of assessment reported ?	Yes				
9	Sample size appropriate?				N/A	
10	Analytic methods described/justified and appropriate?	Yes				
11	Some estimate of variance is reported for the main results?		Yes			
12	Controlled for confounding?				N/A	
13	Results reported in sufficient detail?	Yes				
14	Conclusions supported by the results?	Yes				
Additional information available in the article?						
A	Effects of mixtures (i.e., effects that are not specific to only one chemical)	Yes				Total metal and total PAH exposures were summed
B	Effects of low doses over long periods of time			No		
C	Long- and short-range dispersion and deposition			No		
				Total sum	**17**	
				Total possible sum	**18**	
				Summary score	**0.944444444**	

Scoring
Item score is based on the degree that which the specific criteria are met ("yes" = 2, "partial" = 1, "no" = 0)
Items not applicable to a particular study design are marked "n/a" and are excluded from the scoring
Calculation of summary score:
Total sum = (number of "yes" * 2) + (number of "partials" *1)
Total possible sum = 28 - (number of "n/a" * 2)
Summary score: total sum / total possible sum

1. Kmet LM, Lee RC, and Cook LS. 2004. Standard quality assessment criteria for evaluating primary research papers from a variety of fields. Available at: https://www.ihe.ca/publications/standard-quality-assessment-criteria-for-evaluating-primary-research-papers-from-a-variety-of-fields

Title: Spatial Distribution, Pollution Source, and Health Risk Assessment of Heavy Metals in Atmospheric Depositions: A Case Study from the Sustainable City of Shijiazhuang, China
Author: Cai, Kui; Li, Chang; Na, Sanggyun

Full Article? - Available free online.

Checklist for Assessing the Quality of Quantitative Studies[1]

Criteria		Yes (2)	Partial (1)	No (0)	N/A	Notes
1	Question / objective sufficiently described?	Yes				
2	Study design evident and appropriate ?	Yes				
3	Method of subject/comparison group selection or source of information/input variables described and appropriate ?		Yes			
4	Subject (and comparison group, if applicable) characteristics sufficiently described?		Yes			
5	If random allocation was possible, was it described?				N/A	
6	If blinding of investigators/subjects was possible was it reported?				N/A	
7	Exposure measure(s) well defined and robust to measement /misclassification bias? Means of assessment reported?	Yes				
8	Outcome well defined and robust to measurement/misclassification bias? Means of assessment reported ?	Yes				
9	Sample size appropriate?				N/A	
10	Analytic methods described/justified and appropriate?	Yes				
11	Some estimate of variance is reported for the main results?			No		
12	Controlled for confounding?			No		
13	Results reported in sufficient detail?	Yes				
14	Conclusions supported by the results?	Yes				
Additional information available in the article?						
A	Effects of mixtures (i.e., effects that are not specific to only one chemical)			No		Deals with multiple parameters evaluated in isolation
B	Effects of low doses over long periods of time		Yes			
C	Long- and short-range dispersion and deposition			No		
				Total sum	**16**	
				Total possible sum	**22**	
				Summary score	**0.727272727**	

Scoring
Item score is based on the degree that which the specific criteria are met ("yes" = 2, "partial" = 1, "no" = 0)
Items not applicable to a particular study design are marked "n/a" and are excluded from the scoring
Calculation of summary score:
Total sum = (number of "yes" * 2) + (number of "partials" *1)
Total possible sum = 28 - (number of "n/a" * 2)
Summary score: total sum / total possible sum

1. Kmet LM, Lee RC, and Cook LS. 2004. Standard quality assessment criteria for evaluating primary research papers from a variety of fields. Available at: https://www.ihe.ca/publications/standard-quality-assessment-criteria-for-evaluating-primary-research-papers-from-a-variety-of-fields

Title: Investigation of PM.sub.2.5 absorbed with heavy metal elements, source apportionment and their health impacts in residential houses in the North-east region of China
Author: Bai, Li; He, Zijian; Ni, Shenyang; Chen, Wanyue; Li, Na; Sun, Siyue

Full Article? - Purchased

AFTER REVIEW OF FULL ARTICLE, IT CANNOT BE CONCLUDED THAT EMISSIONS FROM POWER PLANTS/ENERGY GENERATION ARE A SIGNIFICANT SOURCE OF EXPOSURE IN THE STUDY AND WILL NOT BE SUMMARIZED IN THE REPORT

Checklist for Assessing the Quality of Quantitative Studies[1]

	Criteria	Yes (2)	Partial (1)	No (0)	N/A	Notes
1	Question / objective sufficiently described?	Yes				
2	Study design evident and appropriate ?		Yes			
3	Method of subject/comparison group selection or source of information/input variables described and appropriate ?	Yes				
4	Subject (and comparison group, if applicable) characteristics sufficiently described?	Yes				
5	If random allocation was possible, was it described?				N/A	
6	If blinding of investigators/subjects was possible was it reported?				N/A	
7	Exposure measure(s) well defined and robust to meausement /misclassification bias? Means of assessment reported?		Yes			
8	Outcome well defined and robust to measurement/misclassification bias? Means of assessment reported ?		Yes			
9	Sample size appropriate?			No		
10	Analytic methods described/justified and appropriate?		Yes			
11	Some estimate of variance is reported for the main results?			No		
12	Controlled for confounding?			No		
13	Results reported in sufficient detail?		Yes			
14	Conclusions supported by the results?		Yes			
Additional information available in the article?						
A	Effects of mixtures (i.e., effects that are not specific to only one chemical)			No		Deals with multiple parameters evaluated in isolation
B	Effects of low doses over long periods of time		Yes			
C	Long- and short-range dispersion and deposition		Yes			
				Total sum	**12**	
				Total possible sum	**24**	
				Summary score	**0.5**	

Scoring
Item score is based on the degree that which the specific criteria are met ("yes" = 2, "partial" = 1, "no" = 0)
Items not applicable to a particular study design are marked "n/a" and are excluded from the scoring
Calculation of summary score:
Total sum = (number of "yes" * 2) + (number of "partials" *1)
Total possible sum = 28 - (number of "n/a" * 2)
Summary score: total sum / total possible sum

1. Kmet LM, Lee RC, and Cook LS. 2004. Standard quality assessment criteria for evaluating primary research papers from a variety of fields. Available at: https://www.ihe.ca/publications/standard-quality-assessment-criteria-for-evaluating-primary-research-papers-from-a-variety-of-fields

Title: Emission control priority of PM.sub.2.5-bound heavy metals in different seasons: A comprehensive analysis from health risk perspective
Author: Liu, Jianwei; Chen, Yanjiao; Chao, Sihong; Cao, Hongbin; Zhang, Aichen; Yang, Yue

Full Article? - Available free online.

Checklist for Assessing the Quality of Quantitative Studies[1]

	Criteria	Yes (2)	Partial (1)	No (0)	N/A	Notes
1	Question / objective sufficiently described?	Yes				
2	Study design evident and appropriate ?	Yes				
3	Method of subject/comparison group selection or source of information/input variables described and appropriate ?				N/A	No specific group, generic exposure used in risk calculations
4	Subject (and comparison group, if applicable) characteristics sufficiently described?		Yes			US EPA exposure indicated to be used, but not all inputs provided in text
5	If random allocation was possible, was it described?				N/A	
6	If blinding of investigators/subjects was possible was it reported?				N/A	
7	Exposure measure(s) well defined and robust to meansement /misclassification bias? Means of assessment reported?	Yes				
8	Outcome well defined and robust to measurement/misclassification bias? Means of assessment reported ?	Yes				
9	Sample size appropriate?				N/A	
10	Analytic methods described/justified and appropriate?	Yes				
11	Some estimate of variance is reported for the main results?	Yes				
12	Controlled for confounding?				N/A	
13	Results reported in sufficient detail?	Yes				
14	Conclusions supported by the results?	Yes				
Additional information available in the article?						
A	Effects of mixtures (i.e., effects that are not specific to only one chemical)	Yes				Total metal and total PAH exposures were summed
B	Effects of low doses over long periods of time		Yes			Long term exposure considered but concentrations were above national limits
C	Long- and short-range dispersion and deposition			No		
				Total sum	**17**	
				Total possible sum	**18**	
				Summary score	**0.944444444**	

Scoring
Item score is based on the degree that which the specific criteria are met ("yes" = 2, "partial" = 1, "no" = 0)
Items not applicable to a particular study design are marked "n/a" and are excluded from the scoring
Calculation of summary score:
Total sum = (number of "yes" * 2) + (number of "partials" *1)
Total possible sum = 28 - (number of "n/a" * 2)
Summary score: total sum / total possible sum

1. Kmet LM, Lee RC, and Cook LS. 2004. Standard quality assessment criteria for evaluating primary research papers from a variety of fields. Available at: https://www.ihe.ca/publications/standard-quality-assessment-criteria-for-evaluating-primary-research-papers-from-a-variety-of-fields

Title: Environmental impact assessment of monocrystalline silicon solar photovoltaic cell production: a case study in China
Author: Wei Chen, Jinglan Hong, Xueliang Yuan, Jiurong Liu

Full Article? - Purchased

AFTER REVIEW OF FULL ARTICLE, STUDY DOES NOT REPORT HEALTH EFFECTS FROM POWER PLANTS/ENERGY PRODUCTION AND WILL NOT BE SUMMARIZED IN REPORT, HOWEVER IS NOTED OF POTENTIALLY BEING OF GENERAL INTEREST FOR CASA

Checklist for Assessing the Quality of Quantitative Studies[1]

	Criteria	Yes (2)	Partial (1)	No (0)	N/A	Notes
1	Question / objective sufficiently described?	Yes				
2	Study design evident and appropriate ?	Yes				
3	Method of subject/comparison group selection or source of information/input variables described and appropriate ?				N/A	
4	Subject (and comparison group, if applicable) characteristics sufficiently described?				N/A	
5	If random allocation was possible, was it described?				N/A	
6	If blinding of investigators/subjects was possible was it reported?				N/A	
7	Exposure measure(s) well defined and robust to measement /misclassification bias? Means of assessment reported?	Yes				
8	Outcome well defined and robust to measurement/misclassification bias? Means of assessment reported ?	Yes				
9	Sample size appropriate?				N/A	
10	Analytic methods described/justified and appropriate?	Yes				
11	Some estimate of variance is reported for the main results?		Yes			Model reliability was tested
12	Controlled for confounding?				N/A	
13	Results reported in sufficient detail?	Yes				
14	Conclusions supported by the results?	Yes				
Additional information available in the article?						
A	Effects of mixtures (i.e., effects that are not specific to only one chemical)			No		
B	Effects of low doses over long periods of time			No		
C	Long- and short-range dispersion and deposition			No		
				Total sum	**14**	
				Total possible sum	**16**	
				Summary score	**0.875**	

Scoring
Item score is based on the degree that which the specific criteria are met ("yes" = 2, "partial" = 1, "no" = 0)
Items not applicable to a particular study design are marked "n/a" and are excluded from the scoring
Calculation of summary score:
Total sum = (number of "yes" * 2) + (number of "partials" *1)
Total possible sum = 28 - (number of "n/a" * 2)
Summary score: total sum / total possible sum

1. Kmet LM, Lee RC, and Cook LS. 2004. Standard quality assessment criteria for evaluating primary research papers from a variety of fields. Available at: https://www.ihe.ca/publications/standard-quality-assessment-criteria-for-evaluating-primary-research-papers-from-a-variety-of-fields

Title: Health effects of multi-pollutant profiles
Author: Zanobetti, Antonella; Austin, Elena; Coull, Brent A.; Schwartz, Joel; Koutrakis, Petros

Full Article? - Purchased

Checklist for Assessing the Quality of Quantitative Studies[1]

	Criteria	Yes (2)	Partial (1)	No (0)	N/A	Notes
1	Question / objective sufficiently described?	Yes				
2	Study design evident and appropriate ?	Yes				
3	Method of subject/comparison group selection or source of information/input variables described and appropriate ?	Yes				
4	Subject (and comparison group, if applicable) characteristics sufficiently described?			No		Explanation of data source but no details provided
5	If random allocation was possible, was it described?				N/A	
6	If blinding of investigators/subjects was possible was it reported?				N/A	
7	Exposure measure(s) well defined and robust to meausement /misclassification bias? Means of assessment reported?	Yes				
8	Outcome well defined and robust to measurement/misclassification bias? Means of assessment reported ?	Yes				
9	Sample size appropriate?	Yes				
10	Analytic methods described/justified and appropriate?	Yes				
11	Some estimate of variance is reported for the main results?		Yes			
12	Controlled for confounding?			No		
13	Results reported in sufficient detail?		Yes			Sources of clusters provided but individual substances not provided
14	Conclusions supported by the results?	Yes				
Additional information available in the article?						
A	Effects of mixtures (i.e., effects that are not specific to only one chemical)	Yes				
B	Effects of low doses over long periods of time			No		
C	Long- and short-range dispersion and deposition			No		
				Total sum	**18**	
				Total possible sum	**24**	
				Summary score	**0.75**	

Scoring
Item score is based on the degree that which the specific criteria are met ("yes" = 2, "partial" = 1, "no" = 0)
Items not applicable to a particular study design are marked "n/a" and are excluded from the scoring
Calculation of summary score:
Total sum = (number of "yes" * 2) + (number of "partials" *1)
Total possible sum = 28 - (number of "n/a" * 2)
Summary score: total sum / total possible sum

1. Kmet LM, Lee RC, and Cook LS. 2004. Standard quality assessment criteria for evaluating primary research papers from a variety of fields. Available at: https://www.ihe.ca/publications/standard-quality-assessment-criteria-for-evaluating-primary-research-papers-from-a-variety-of-fields

APPENDIX D

Studies of Interest to Address Data Gaps

Classification: Protected A

APPENDIX D
Table D1: Effects of Mixtures

Title	Year	Author
Identified via Specific Search		
Gene expression profiling of human bronchial epithelial cells exposed to fine particulate matter ($PM_{2.5}$) from biomass combustion.	2018	Popadić, Désirée; Heßelbach, Katharina; Richter-Brockmann, Sigrid; Kim, Gwang-Jin; Flemming, Stephan; Schmidt-Heck, Wolfgang; Häupl, Thomas; Bonin, Marc; Dornhof, Regina; Achten, Christine; Günther, Stefan; Humar, Matjaz; Merfort, Irmgard
Health effects of multi-pollutant profiles	2014	Zanobetti, Antonella; Austin, Elena; Coull, Brent A.; Schwartz, Joel; Koutrakis, Petros
Identified via General Searches		
Profile of PAHs in the inhalable particulate fraction: source apportionment and associated health risks in a tropical megacity	2013	Sarkar S; Khillare PS
Status, sources, and human health risk assessment of PAHs via foliar dust from different functional areas in Nanjing, China	2018	Yan Zha, Yin L. Zhang, Jie Tang & Kai Sun
Source Identification and Health Risk Assessment of Polycyclic Aromatic Hydrocarbon-Enriched $PM_{2.5}$ in Tangshan, China	2019	Zhang L; Xu H; Fang B; Wang H; Yang Z; Yang W; Hao Y; Wang X; Wang Q; Wang M
Comparative study of PM_{10}-bound heavy metals and PAHs during six years in a Chinese megacity: Compositions, sources, and source-specific risks	2019	Xue, Qianqian; Jiang, Zhuo; Wang, Xiang; Song, Danlin; Huang, Fengxia; Tian, Yingze; Huang-fu, Yanqi; Feng, Yinchang
Characteristics, sources and health risks of toxic species (PCDD/Fs, PAHs and heavy metals) in $PM_{2.5}$ during fall and winter in an industrial area	2020	Bi, Chenglu; Chen, Yantong; Zhao, Zhuzi; Li, Qing; Zhou, Quanfa; Ye, Zhaolian; Ge, Xinlei
Variations of emission characterization of PAHs emitted from different utility boilers of coal-fired power plants and risk assessment related to atmospheric PAHs.	2015	Wang, Ruwei; Liu, Guijian; Zhang, Jiamei
Residuals, bioaccessibility and health risk assessment of PAHs in winter wheat grains from areas influenced by coal combustion in China.	2018	Tian, Kai; Bao, Huanyu; Zhang, Xuechen; Shi, Taoran; Liu, Xueping; Wu, Fuyong
Sources, environmental levels, and health risks of $PM_{2.5}$ -bound polycyclic aromatic hydrocarbons in energy-producing cities in northern China.	2020	Guo L; Hu J; Xing Y; Wang H; Miao S; Meng Q; Wang X; Bai S; Jia J; Wang P; Zhang R; Gao P
Diurnal concentrations, sources, and cancer risk assessments of $PM_{2.5}$-bound PAHs, NPAHs, and OPAHs in urban, marine and mountain environments	2018	Junmei Zhang, Lingxiao Yang, Abdelwahid Mellouki, Jianmin Chen, Xiangfeng Chen, Ying Gao, Pan Jiang, Yanyan Li, Hao Yu, Wenxing Wang
Implications of seasonal control of $PM_{2.5}$ -bound PAHs: An integrated approach for source apportionment, source region identification and health risk assessment.	2019	Chao S; Liu J; Chen Y; Cao H; Zhang A
Source apportionment and risk assessment of polycyclic aromatic hydrocarbons in the atmospheric environment of Alexandria, Egypt.	2013	Khairy MA; Lohmann R
Source apportionment of atmospheric PAHs and their toxicity using PMF: Impact of gas/particle partitioning.	2015	Gao, Bo; Wang, Xin-Ming; Zhao, Xiu-Ying; Ding, Xiang; Fu, Xiao-Xin; Zhang, Yan-Li; He, Quan-Fu; Zhang, Zhou; Liu, Teng-Yu; Huang, Zou-Zhao; Chen, Lai-Guo; Peng, Yan; Guo, Ha
Polycyclic aromatic hydrocarbons (PAHs) in urban soils of the megacity Shanghai: Occurrence, source apportionment and potential human health risk	2013	Wang, Xue-Tong; Miao, Yi; Zhang, Yuan; Li, Yuan-Cheng; Wu, Ming-Hong; Yu, Gang
Seasonal variation, sources and health risk assessment of polycyclic aromatic hydrocarbons in different particle fractions of $PM_{2.5}$ in Beijing, China	2019	Song, Haojun; Zhang, Yang; Luo, Min; Gu, Jianzhong; Wu, Minghong; Xu, Diandou; Xu, Gang; Ma, Lingling
Microscale spatial distribution and health assessment of $PM_{2.5}$-bound polycyclic aromatic hydrocarbons (PAHs) at nine communities in Xi'an, China	2016	Xu, Hongmei; Ho, Steven Sai Hang; Gao, Meiling; Cao, Junji; Guinot, Benjamin; Ho, Kin Fai; Long, Xin; Wang, Jingzhi; Shen, Zhenxing; Liu, Suixin; Zheng, Chunli; Zhang, Qian
Characteristics, sources and health risk assessment of airborne particulate PAHs in Chinese cities: A review	2019	Yan, Daohao; Wu, Shaohua; Zhou, Shenglu; Tong, Guijie; Li, Fufu; Wang, Yuanmin; Li, Baojie
Characterization of $PM_{2.5}$-Bound Polycyclic Aromatic Hydrocarbons at Two Central China Cities: Seasonal Variation, Sources, and Health Risk Assessment	2020	Qun Wang, Zhangsen Dong, Yue Guo, Fei Yu, Zhenya Zhang, Ruiqin Zhang

Table D2: Effects of Low Doses Over Long Periods of Time

Title	Year	Author
Identified via Specific Search		
The assessment of health impacts and external costs of natural gas-fired power plant of Qom.	2016	Fouladi-Fard, Reza; Naddafi, Kazem; Yunesian, Masuc Nabizadeh Nodehi, Ramin; Dehghani, Mohammad; Hassanvand, Mohammac
The contribution of outdoor air pollution sources tc premature mortality on a global scal	2015	Lelieveld, J.; Evans, J.S.; Fnais, M.; Giannadaki, D.; Pozzer, A.
Impact of air pollution on the burden of chronic respirator diseases in China: time for urgent actio	2016	Guan, Wei-Jie; Zheng, Xue-Yan; Chung, Kian Fan; Zhong, Nar Shan
Identified via General Searches		
$PM_{2.5}$-related health impacts of utilizing ammonia-hydrogen energy in Kanto Region, Japan	2018	Lu, Mengqian; Lin, Bin-Le; Inoue, Kazuya; Lei, Zhongfang; Zhang, Zhenya; Tsunemi, Kiyotaka
Association of $PM_{2.5}$ with diabetes, asthma, and high blood pressure incidence in Canada: A spatiotemporal analysis of the impacts of the energy generation and fuel sales	2017	Requia, Weeberb J; Adams, Matthew D; Koutrakis, Petros
Sex differences in the association between exposure to indoor particulate matter and cognitive control among children (age 6–14 years) living near coal-fired power plants.	2020	Sears, Clara G.; Sears, Lonnie; Zierold, Kristina M.
Contribution of nitrogen oxide and sulfur dioxide exposur from power plant emissions on respiratory symptom and disease prevalence	2014	Amster, Eric D.; Haim, Maayan; Dubnov, Jonathan; Broday, David M.
External costs of atmospheric lead emissions from a waste to-energy plant: A follow-up assessment of indirect exposur via topsoil ingestior	2013	Pizzol, Massimo; Møller, Flemming; Thomsen, Marianne
Emission control priority of $PM_{2.5}$-bound heavy metals in different seasons: A comprehensive analysis from health risk perspective	2018	Liu, Jianwei; Chen, Yanjiao; Chao, Sihong; Cao, Hongbin; Zhang, Aichen; Yang, Yue
Air pollution and early deaths in the United States. Part I: Quantifying the impact of major sectors in 200	2013	Fabio Caiazzo, Akshay Ashok, Ian A. Waitz, Steve H.L. Yim, Steven R.H. Barret

Table D3: Long- and Short-Range Dispersion and Deposition

Title	Year	Author
White Literature Identified via Specific Search		
The effect of heat recovery on near-source plume dispersion of a simple cycle gas turbine	2018	Yang, Bo; Gu, Jiajun; Zhang, K. Max
Deposition prediction in a pilot scale pulverized fuel-fired combustor	2019	Riccio, C.; Simms, N.J.; Oakey, J.E.
SO_2 Disperson Modeling Emitted From Hongsa Coal-Fired Power Plant Transboundary to Nan Province, Thailand.	2020	Srirattana, Supawan; Piaowan, Kitsanateen
Modelling of hydrogen sulfide dispersion from the geothermal power plants of Tuscany (Italy).	2017	Somma, Renato; Granieri, Domenico; Troise, Claudia; Terranova, Carlo; De Natale, Giuseppe; Pedone, Maria
Spatiotemporal patterns of the fossil-fuel CO_2 signal in central Europe: results from a high-resolution atmospheric transport model.	2017	Yu Liu; Gruber, Nicolas; Brunner, Dominik
Soil as an archive of coal-fired power plant mercury deposition.	2016	Rodríguez Martín, José Antonio; Nanos, Nikos
Impacts of the Minamata Convention on Mercury Emissions and Global Deposition from Coal-Fired Power Generation in Asia.	2015	Giang, Amanda; Stokes, Leah C.; Streets, David G.; Corbitt, Elizabeth S.; Selin, Noelle E.
Strategic combustion technology with exhaust tube vortex flame: Combined effect of biomass co-firing and air-staged combustion on combustion characteristics and ash deposition.	2020	Choi, Minsung; Kim, Kibeom; Li, Xinzhuo; Deng, Kaiwen; Park, Yeseul; Seo, Minseok; Sung, Yonmo; Choi, Gyungmin
Atmospheric Dispersion of Radioactivity from Nuclear Power Plant Accidents: Global Assessment and Case Study for the Eastern Mediterranean and Middle East.	2014	Christoudias, Theodoros; Proestos, Yiannis; Lelieveld, Jos
White Literature Identified via General Searches		
Near-source air quality impact of a distributed natural gas combinedheat and power facility.	2019	Bo Yang, Jiajun Gu, Tong Zhang, K. Max Zhang
Emission characteristics of condensable particulate matter and sulfur trioxide from coal-fired power plants	2020	Yang, Fuxin; Li, Zhenghong; Liu, Hexin; Feng, Peng; Tan, Houzhang; Zhang, Sicong; Lu, Xuchao
Migration and distribution characteristics of organic and inorganic fractions in condensable particulate matter emitted from an ultralow emission coal-fired power plant	2020	Song, Jianwu; Lu, Shengyong; Wu, Yujia; Zhou, Chenyang; Li, Xiaodong; Li, Jingwei
The impacts of coal plants relocation on the concentration of fine particulate matter in China.	2016	Dunguo Mou; Herington, Matthew; Omoju, Oluwasola E.
The impact of photovoltaic (PV) installations on downwind particulate matter concentrations: Results from field observations at a 550-MWAC utility-scale PV plant.	2017	Ravikumar, Dwarakanath; Sinha, Parikhit
Air Pollution Inequality and Its Sources in SO_2 and NO_X Emissions among Chinese Provinces from 2006 to 2015	2018	Mohaddeseh Azimi; Feng Feng; Yang Yang
Estimates of community exposure and health risk to sulfur dioxide from power plant emissions using short-term mobile and stationary ambient air monitoring.	2015	Shepherd, Mark A.; Haynatzki, Gleb; Rautiainen, Risto; Achutan, Chandran
Spatial and temporal evaluation of H_2S, SO_2 and NH_3 concentrations near Cerro Prieto geothermal power plant in Mexico	2019	Aguilar-Dodier, L.C.; Castillo, J.E.; Quintana, Penelope J.E.; Montoya, Lupita D.; Molina, Luisa T.; Zavala, Miguel; Almanza-Veloz, V.; Rodríguez-Ventura, J.G.
Spatial pollution rose pattern of SO_2 in the vicinity of a typical thermal power station in India.	2020	Iyyappan, M.; Kumaravel, B.; Bhakiyaraja, S.; Palanivelraja, S.; Chockalingam, M. P.; Pitchandi, P; Shakya, Subarna
C-Sr-Pb isotopic characteristics of $PM_{2.5}$ transported on the East-Asian continental outflows	2019	Jung, Chien-Cheng; Chou, Charles C.-K.; Lin, Chuan-Yao; Shen, Chuan-Chou; Lin, Yu-Chi; Huang, Yi-Tang; Tsai, Chao-Yang; Yao, Pei-Hsuan; Huang, Ci-Rong; Huang, Wei-Ru; Chen, Mei-June; Huang, Shu-Hui; Chang, Shuen-Chin
Distribution of atmospheric mercury in northern Southeast Asia and South China Sea during Dongsha Experiment	2013	Sheu, Guey-Rong; Lin, Neng-Huei; Lee, Chung-Te; Wang, Jia-Lin; Chuang, Ming-Tung; Wang, Sheng-Hsiang; Chi, Kai Hsine; Ou-Yang, Chang-Feng
Effects of heating activities in winter on characteristics of $PM_{2.5}$-bound Pb, Cd and lead isotopes in cities of China	2020	Deng, Lin; Bi, Chunjuan; Jia, Jinpu; Zeng, Yongsheng; Chen, Zhenlou
Gauging intraurban variability of ambient particulate matter arsenic and other air toxic metals from a network of monitoring sites	2014	Yadav, Varun; Turner, Jay
Impact assessment of biomass burning on air quality in Southeast and East Asia during BASE-ASIA	2013	Huang, Kan; Fu, Joshua S.; Hsu, N. Christina; Gao, Yang; Dong, Xinyi; Tsay, Si-Chee; Lam, Yun Fat
Source indicators of biomass burning associated with inorganic salts and carboxylates in dry season ambient aerosol in Chiang Mai Basin, Thailand	2012	Tsai, Ying I.; Sopajaree, Khajornsak; Chotruksa, Auranee; Wu, Hsin-Ching; Kuo, Su-Ching

Table D3: Long- and Short-Range Dispersion and Deposition

Title	Year	Author
Spatiotemporal variations and potential sources of tropospheric formaldehyde over eastern China based on OMI satellite data	2020	Fan, Jiachen; Ju, Tianzhen; Wang, Qinhua; Gao, Haiyan; Huang, Ruirui; Duan, Jiale
Atmospheric deposition of mercury and cadmium impacts on topsoil in a typical coal mine city, Lianyuan, China.	2017	Liang, Jie; Feng, Chunting; Zeng, Guangming; Zhong, Minzhou; Gao, Xiang; Li, Xiaodong; He, Xinyue; Li, Xin; Fang, Yilong; Mo, Dan
Contributions to local- and regional-scale formaldehyde concentrations.	2018	Bastien, Lucas A. J.; Brown, Nancy J.; Harley, Robert A.
Dispersion modeling of particulate matter containing hexavalent chromium during high winds in southern Iraq.	2015	Zannetti, Paolo; Daly, Aaron D.; Freedman, Frank R.
Metallic elements and Pb isotopes in $PM_{2.5}$ in three Chinese typical megacities: spatial distribution and source apportionment.	2020	Xu, H. M.; He, K. L.; Feng, R.; Shen, Z. X.; Cao, J. J.; Liu, S. X.; Ho, K. F.; Huang, R.-J.; Guinot, B.; Wang, Q. Y.; Zhou, J. M.; Shen, M. X.; Xiao, S.; Zhou, B. H.; Sonke, J. E.
Tracking long-distance atmospheric deposition of trace metal emissions from smelters in the upper Columbia River valley using Pb isotope analysis of lake sediments.	2018	Child, Andrew Wright; Moore, Barry C.; Vervoort, Jeffrey D.; Beutel, Marc W.
Sources and mass inventory of sedimentary polycyclic aromatic hydrocarbons in the Gulf of Thailand: Implications for pathways and energy structure in SE Asia	2017	Hu, Limin; Shi, Xuefa; Qiao, Shuqing; Lin, Tian; Li, Yuanyuan; Bai, Yazhi; Wu, Bin; Liu, Shengfa; Kornkanitnan, Narumol; Khokiattiwong, Somkiat
Survey of atmospheric deposition of Al, Cr, Fe, Ni, V, and Zn in Albania by using moss biomonitoring and ICP-AES.	2014	Qarri, Flora; Lazo, Pranvera; Stafilov, Trajce; Bekteshi, Lirim; Baceva, Katerina; Marka, Jani
Mapping of atmospheric heavy metal deposition in Guangzhou city, southern China using archived bryophytes	2020	Wu, Liqin; Fu, Shanming; Wang, Xiaohong; Chang, Xiangyang
Source-specific speciation profiles of $PM_{2.5}$ for heavy metals and their anthropogenic emissions in China	2018	Liu, Yayong; Xing, Jia; Wang, Shuxiao; Fu, Xiao; Zheng, Haotian
Quantifying missing annual emission sources of heavy metals in the United Kingdom with an atmospheric transport model	2014	Dore, Anthony J.; Hallsworth, Stephen; McDonald, Alan G.; Werner, Małgorzata; Kryza, Maciej; Abbot, John; Nemitz, Eiko; Dore, Christopher J.; Malcolm, Heath; Vieno, Massimo; Reis, Stefan; Fowler, David
Emission, mass balance, and distribution characteristics of PCDD/Fs and heavy metals during cocombustion of sewage sludge and coal in power plants.	2013	Zhang G; Hai J; Ren M; Zhang S; Cheng J; Yang Z
Heavy metals in the air and snow cover of Ulan Bator	2013	Sorokina, O. I.; Kosheleva, N. E.; Kasimov, N. S.; Golovanov, D. L.; Bazha, S. N.; Dorzhgotov, D.; Enkh-Amgalan, S.
Soil heavy metal(loid)s and risk assessment in vicinity of a coal mining area from southwest Guizhou, China	2016	Qin, Fan-xin; Wei, Chao-fu; Zhong, Shou-qin; Huang, Xian-fei; Pang, Wen-pin; Jiang, Xin
Pollution indices and sources appointment of heavy metal pollution of agricultural soils near the thermal power plant.	2019	Saljnikov E; Mrvić V; Čakmak D; Jaramaz D; Perović V; Antić-Mladenović S; Pavlović P
Assessment of Metal Immission in Urban Environments Using Elemental Concentrations and Zinc Isotope Signatures in Leaves of Nerium oleander.	2018	Martín, A.; Caldelas, C.; Weiss, D.; Aranjuelo, I.; Navarro, E.
Fine Particle Iron in Soils and Road Dust Is Modulated by Coal-Fired Power Plant Sulfur.	2020	Wong JPS; Yang Y; Fang T; Mulholland JA; Russell AG; Ebelt S; Nenes A; Weber RJ
Gaseous Elemental Mercury Level and Distribution in a Heavily Contaminated Site: the Ex-chlor Alkali Plant in Torviscosa (Northern Italy).	2017	Acquavita, Alessandro; Biasiol, Stefano; Lizzi, Daniel; Mattassi, Giorgio; Pasquon, Mariangela; Skert, Nicola; Marchiol, Luca
Isotopic Tracing of Thallium Contamination in Soils Affected by Emissions from Coal-Fired Power Plants.	2016	Vaněk, Aleš; Grösslová, Zuzana; Mihaljevič, Martin; Trubač, Jakub; Ettler, Vojtěch; Teper, Leslaw; Cabala, Jerzy; Rohovec, Jan; Zádorová, Tereza; Penížek, Vít; Pavlů, Lenka; Holubík, Ondřej; Němeček, Karel; Houška, Jakub; Drábek, Ondřej; Ash, Christopher
Modelling spatial variation of fluoride pollutant using geospatial approach in the surrounding environment of an aluminium industries.	2015	Pandey, Prem; Kumar, Pavan; Tomar, Vandana; Rani, Meenu; Katiyar, Swati; Nathawat, Mahendra
Thermodynamic and environmental impact assessment of steam methane reforming and magnesium-chlorine cycle-based multigeneration systems.	2015	Ozcan, Hasan; Dincer, Ibrahim
Emission and profile characteristic of volatile organic compounds emitted from coke production, iron smelt, heating station and power plant in Liaoning Province, China.	2015	Shi, Jianwu; Deng, Hao; Bai, Zhipeng; Kong, Shaofei; Wang, Xiuyan; Hao, Jiming; Han, Xinyu; Ning, Ping
Airborne Observations of Reactive Inorganic Chlorine and Bromine Species in the Exhaust of Coal-Fired Power Plants.	2018	Lee BH; Lopez-Hilfiker FD; Schroder JC; Campuzano-Jost P; Jimenez JL; McDuffie EE; Fibiger DL; Veres PR; Brown SS; Campos TL; Weinheimer AJ; Flocke FF; Norris G; O'Mara K; Green JR; Fiddler MN; Bililign S; Shah V; Jaeglé L; Thornton JA
Biological CO_2 mitigation from coal power plant by Chlorella fusca and Spirulina sp.	2017	Duarte JH; de Morais EG; Radmann EM; Costa JAV

Table D3: Long- and Short-Range Dispersion and Deposition

Title	Year	Author
Long-term monitoring of airborne nickel (Ni) pollution in association with some potential source processes in the urban environment.	2014	Kim KH; Shon ZH; Mauulida PT; Song SK
Biomonitoring of polycyclic aromatic hydrocarbons in urban and industrial environments of the Western Black Sea Region, Turkey.	2014	Çabuk H; Kılıç MS; Ören M
Polychlorinated biphenyls, polychlorinated dibenzo-p-dioxins and dibenzofurans, and polycyclic aromatic hydrocarbons around a thermal desorption plant in China.	2015	Liu J; Li X; Chen T; Qi Z; Buekens A; Lu S; Yan J
Differential accumulation of PAHs, elements, and Pb isotopes by five lichen species from the Athabasca Oil Sands Region in Alberta, Canada.	2017	Graney, Joseph R.; Landis, Matthew S.; Puckett, Keith J.; Studabaker, William B.; Edgerton, Eric S.; Legge, Allan H.; Percy, Kevin E.
Particle/Gas Partitioning of Phthalates to Organic and Inorganic Airborne Particles in the Indoor Environment.	2018	Wu Y; Eichler CMA; Cao J; Benning J; Olson A; Chen S; Liu C; Vejerano EP; Marr LC; Little JC
Seasonal variation and potential source regions of $PM_{2.5}$ -bound PAHs in the megacity Beijing, China: Impact of regional transport.	2017	Zhang Y; Chen J; Yang H; Li R; Yu Q
Polycyclic aromatic hydrocarbons (PAHs) in urban soils of the megacity Shanghai: Occurrence, source apportionment and potential human health risk	2018	Wang, Xue-Tong; Miao, Yi; Zhang, Yuan; Li, Yuan-Cheng; Wu, Ming-Hong; Yu, Gang
The occurrence and source evaluation of polycyclic aromatic hydrocarbons in urban atmosphere using moss biomonitor and GC-MS analysis	2017	Rotaru, Andreea; Reizer, Edina; Panescu, Vlad; Pop, Sorin; Beldean-Galea, Mihail Simion
Life cycle environmental impact comparison of solid oxide fuel cells fueled by natural gas, hydrogen, ammonia and methanol for combined heat and power generation	2020	Bicer, Yusuf; Khalid, Farrukh
Polycyclic aromatic hydrocarbons in tree barks, gaseous and particulate phase samples collected near an industrial complex in São Paulo (Brazil).	2019	Pereira GM; Ellen da Silva Caumo S; Mota do Nascimento EQ; Parra YJ; de Castro Vasconcellos P
Levels, trends and health concerns of atmospheric PAHs in Europe	2014	Garrido, Adrián; Jiménez-Guerrero, Pedro; Ratola, Nuno
Source apportionment and toxicity of atmospheric polycyclic aromatic hydrocarbons by PMF: Quantifying the influence of coal usage in Taiyuan, China	2017	Yan, Yulong; He, Qiusheng; Guo, Lili; Li, Hongyan; Zhang, Hefeng; Shao, Min; Wang, Yuhang
Structural equation modeling of PAHs in ambient air, dust fall, soil, and cabbage in vegetable bases of Northern China	2018	Zhang, YunHui; Hou, DeYi; Xiong, GuanNan; Duan, YongHong; Cai, ChuanYang; Wang, Xin; Li, JingYa; Tao, Shu; Liu, WenXin
Occurrence of polycyclic aromatic hydrocarbons (PAHs) in air and soil surrounding a coal-fired thermal power plant in the south-west coast of India	2019	Gune, Minal Milind; Ma, Wan-Li; Sampath, Srimurali; Li, Wenlong; Li, Yi-Fan; Udayashankar, Harikripa Narayana; Balakrishna, Keshava
Polycyclic Aromatic Hydrocarbons in the Environment: Environmental Fate and Transformation	2013	Sergio Manzetti
Status, sources, and human health risk assessment of PAHs via foliar dust from different functional areas in Nanjing, China	2018	Yan Zha, Yin L. Zhang, Jie Tang & Kai Sun
Linking sources to early effects by profiling urine metabolome of residents living near oil refineries and coal-fired power plants	2017	Chen, Chi-Hsin Sally; Yuan, Tzu-Hsuen; Shie, Ruei-Hao; Wu, Kuen-Yuh; Chan, Chang-Chuan
External costs of atmospheric lead emissions from a waste-to-energy plant: A follow-up assessment of indirect exposure via topsoil ingestion	2013	Pizzol, Massimo; Møller, Flemming; Thomsen, Marianne
Residuals, bioaccessibility and health risk assessment of PAHs in winter wheat grains from areas influenced by coal combustion in China.	2018	Tian, Kai; Bao, Huanyu; Zhang, Xuechen; Shi, Taoran; Liu, Xueping; Wu, Fuyong
Polycyclic aromatic hydrocarbons (PAHs) in urban soils of the megacity Shanghai: Occurrence, source apportionment and potential human health risk	2013	Wang, Xue-Tong; Miao, Yi; Zhang, Yuan; Li, Yuan-Cheng; Wu, Ming-Hong; Yu, Gang
Seasonal variation, sources and health risk assessment of polycyclic aromatic hydrocarbons in different particle fractions of $PM_{2.5}$ in Beijing, China	2019	Song, Haojun; Zhang, Yang; Luo, Min; Gu, Jianzhong; Wu, Minghong; Xu, Diandou; Xu, Gang; Ma, Lingling
Grey Literature Identified via General Searches		
Acid and Mercury Deposition	Website, no date provided	New York State Energy Research and Development Authority
Toxic substances list: mercury	2020	Environment and Climate Change Canada; search bar
Canadian mercury science assessment: executive summary	2017	Environment and Climate Change Canada; search bar
Tackling mercury pollution in the EU and worldwide	2017	European Commission – Environment

APPENDIX E

References and Abstracts

Classification: Protected A

Reference	Abstract	URL	Peer Reviewed (Yes/No)
Amster ED, Haim M, Dubnov J, Broday DM. 2014. Contribution of nitrogen oxide and sulfur dioxide exposure from power plant emissions on respiratory symptom and disease prevalence. Environmental Pollution 186: 20-28.	This study investigates the association between exposure to ambient NO_x and SO_2 originating from power plant emissions and prevalence of obstructive pulmonary disease and related symptoms. The Orot Rabin coal-fired power plant is the largest power generating facility in the Eastern Mediterranean. Two novel methods assessing exposure to power plant-specific emissions were estimated for 2244 participants who completed the European Community Respiratory Health Survey. The “source approach” modeled emissions traced back to the power plant while the “event approach” identified peak exposures from power plant plume events. Respiratory symptoms, but not prevalence of asthma and COPD, were associated with estimates of power plant NO_x emissions. The “source approach” yielded a better estimate of exposure to power plant	https://www.sciencedirect.com/science/article/abs/pii/S0269749113005605	Yes
Bi C, Chen Y, Zhao Z, Li Q, Zhou Q, Ye Z, Ge X. 2020. Characteristics, sources and health risks of toxic species (PCDD/Fs, PAHs and heavy metals) in PM2.5 during fall and winter in an industrial area. Chemosphere 238: 124620.	Particulate toxic species, such as polychlorinated dibenzo-p-dioxins and polychlorinated dibenzofurans (PCDD/Fs), polycyclic aromatic hydrocarbons (PAHs) and heavy metals may have significant health risks. This study investigated characteristics, sources and health risks of all three classes of toxic species in PM2.5 (particles with aerodynamic diameter ≤2.5 μm) samples collected at an industrial area in Changzhou, a big city in the Yangtze Delta region of China. Fourteen heavy metals altogether constituted 2.87% of PM2.5 mass, with Fe, Al and Zn as the major elements. Principal component analysis (PCA) suggested that heavy metals came from four sources: vehicles, industry, crustal dust, mixed coal combustion and industrial process. The daily average concentration of 18 PAHs was 235.29 ng/m^3, accounting for 0.21% of PM2.5 mass. The dominant PAHs were high molecular weight ones, contributing 73.5% to the total PAHs. Diagnostic analyses indicated that sources of PAHs included vehicle/coal combustion and petroleum emissions, wherein diesel emission played a more important role than gasoline emission. PCA showed that the largest contributor of PAHs was vehicle exhaust mixed with coal combustion, followed by three industry-related sources. Total concentration of 17 PCDD/Fs varied between 3.14 and 37.07	https://www.sciencedirect.com/science/article/abs/pii/S0045653519318442	Yes
Cai K, Li C, Na S. 2019. Spatial distribution, pollution source, and health risk assessment of heavy metals in atmospheric depositions: A case study from the sustainable city of Shijiazhuang, China. Atmosphere 10 (4): 222.	Samples of atmospheric depositions from five types of functional areas in Shijiazhuang, Hebei Province, China, were collected, and the concentrations of six toxic heavy metals (Cd, Cr, Cu, Pb, Ni, and Zn) were measured. Geographic information system, Pb isotope assessment, multivariate statistical analysis (principal component analysis, PCA), the geoaccumulation index (Igeo), potential ecological risk index (PERI), and a health risk assessment model were used to study the degree of pollution, identify sources of pollution, and assess the health risks to children and adults via three pathways (hand–mouth intake, skin contact, and respiration). The results show that the high traffic volume and exhaust gas emissions have led to high concentrations of heavy metals. The Igeo and PERI values of Cd (0.38–2.0 and 108–4531, respectively), indicating the present high pollution level and potential risk, respectively, varied the most. Pb isotope and PCA showed that	https://www.mdpi.com/2073-4433/10/4/222	Yes
Caiazzo F, Ashok A, Waitz IA, Yim SHL, Barrett SRH. 2013. Air pollution and early deaths in the United States. Part I: Quantifying the impact of major sectors in 2005. Atmospheric Environment 79 (2013): 198-208.	Combustion emissions adversely impact air quality and human health. A multiscale air quality model is applied to assess the health impacts of major emissions sectors in United States. Emissions are classified according to six different sources: electric power generation, industry, commercial and residential sources, road transportation, marine transportation and rail transportation. Epidemiological evidence is used to relate long-term population exposure to sector-induced changes in the concentrations of PM2.5 and ozone to incidences of premature death. Total combustion emissions in the U.S. account for about 200,000 (90% CI: 90,000-362,000) premature deaths per year in the U.S. due to changes in PM2.5 concentrations, and about 10,000 (90% CI: -1000 to 21,000) deaths due to changes in ozone concentrations. The largest contributors for both pollutant-related mortalities are road transportation, causing ~53,000 (90% CI: 24,000-95,000) PM2.5-related deaths and w5000 (90% CI: -900 to 11,000) ozonerelated early deaths per year, and power generation, causing ~52,000 (90% CI: 23,000-94,000) PM2.5-related and ~2000 (90% CI: -300 to 4000) ozone-related premature mortalities per year. Industrial emissions contribute to ~41,000 (90% CI: 18,000-74,000) early deaths from PM2.5 and ~2000 (90% CI: 0-4000) early deaths from ozone. The results are indicative of the extent to which policy measures could be undertaken in order to mitigate the impact of specific emissions from different sectors d in particular black carbon emissions from road transportation and sulfur dioxide emissions from power generation.	https://www.sciencedirect.com/science/article/abs/pii/S1352231013004548	Yes
Chao S, Liu J, Chen Y, Cao H, Zhang A. 2019. Implications of seasonal control of PM 2.5-bound PAHs: An integrated approach for source apportionment, source region identification and health risk assessment. Environmental pollution (Barking, Essex : 1987) 247: 685-695.	PM 2.5 -bound PAHs are ubiquitous in urban atmospheres and are characterized as carcinogenic, teratogenic and mutagenic upon inhalation. A total of 218 daily PM 2.5 samples were collected during one year in the urban district of Beijing, China. Analysis showed that the annual mean concentration of total PAHs (TPAHs) was 66.2 ng/m 3 , with benzo(a)pyrene (BaP) accounting for 12.4%. High-molecular-weight (HMW, 4-6 rings) PAHs were the dominant components. Seasonal TPAH concentrations decreased in the order of heating season (156 ng/m 3) > autumn (20.4 ng/m 3) > spring (16.0 ng/m 3) > summer (12.5 ng/m 3) and were related to meteorological conditions and source emission intensity. The source-attributed mass contribution and source regions of three sources (i.e., (1) vehicle emissions; (2) coal combustion; and (3) petroleum volatilization, natural gas and biomass combustion) were identified by integrating the positive matrix factorization (PMF), potential source contribution function (PSCF) and conditional probability function (CPF). Vehicle emissions contributed the most mass (54.6%), followed by coal combustion (29.8%), on an annual basis. Combined with actual regional emissions, vehicle emissions were mainly derived from local sources, while coal combustion mainly came from regional transport from surrounding areas. Vehicle emissions and coal combustion have much higher mass contributions in the heating season. The source-attributed cancer risk was further evaluated based on source mass contribution and inhalation unit risk. Vehicle emissions contributed the largest risk (2.8 × 10 -6 , accounting for 71%) as a result of 30 years of exposure for local residents, exceeding the acceptable level (10 -6). The heating season showed the most risk, especially in response to vehicle emissions and coal combustion. Overall, the source-attributed cancer risk was regarded as the better index for the development of a control strategy of PM 2.5 -bound PAHs for protecting residents. Based on this index, priority control sources in each season were identified to supply a more effective management solution.	https://www.sciencedirect.com/science/article/abs/pii/S0269749118342490	Yes
Chen CHS, Yuan TH, Shie RH, Wu KY, Chan CC. 2017. Linking sources to early effects by profiling urine metabolome of residents living near oil refineries and coal-fired power plants. Environment International 102: 87-96.	This study aims at identifying metabolic changes linking external exposure to industrial air toxics with oxidative stress biomarkers. We classified 252 study subjects as 111 high vs. 141 low exposure subjects by the distance from their homes to the two main emission sources, oil refineries and coal-fired power plants. We estimated individual's external exposure to heavy metals and polycyclic aromatic hydrocarbons (PAHs) by dispersion and kriging models, respectively. We measured urinary levels of heavy metals and 1-hydroxypyrene (1-OHP) as biomarkers of internal exposure, and 8-OHdG, HNE-MA, 8-isoPGF2a, and 8-NO2Gua as biomarkers of early health effects. We used two-dimensional gas chromatography time-of-flight mass spectrometry to identify urine metabolomics. We applied 'meet-in-the-middle' approach to identify potential metabolites as putative intermediate biomarkers linking multiple air toxics exposures to oxidative stress with plausible exposures-related pathways. High exposure subjects showed elevated ambient concentrations of vanadium and PAHs, increased urine concentrations of 1-OHP, vanadium, nickel, copper, arsenic, strontium, cadmium, mercury, and thallium, and higher urine concentrations of all four urine oxidative stress biomarkers compared to low exposure subjects. We identified a profile of putative intermediate biomarkers that were associated with both exposures and oxidative stress biomarkers in participants. Urine metabolomics identified age-dependent biological pathways, including tryptophan metabolism and phenylalanine metabolism in children subjects (aged 9--11), and glycine, serine, and threonine metabolism in elderly subjects (aged > 55), that could associate multiple exposures with oxidative stress. By profiling urine biomarkers and metabolomics in children and elderly residents living near a petrochemical complex, we can link their internal exposure to oxidative stress biomarkers through biological pathways associated with common complex chronic diseases and allergic respiratory diseases. The internal exposure may possibly be traced to multiple air toxics emitted from specific sources of oil refineries and coal-fired	https://www.sciencedirect.com/science/article/pii/S0160412016307528	Yes
Ewald B. 2018. The value of health damage due to sulphur dioxide emissions from coal-fired electricity generation in NSW and implications for pollution licences. Australian and New Zealand journal of public health 42 (3): 227-229.	Not available	https://pubmed.ncbi.nlm.nih.gov/29644782/	Yes
Fouladi FR, Naddafi K, Yunesian M, Nabizadeh NR, Dehghani M, Hassanvand M. 2016. The assessment of health impacts and external costs of natural gas-fired power plant of Qom. Environmental Science & Pollution Research 23 (20): 20922-20936.	The external health damage costs of the combined cycle natural gas-fired power plant of Qom were investigated via the simplified impact pathway approach. Emitted particulate matter (PM) and gaseous pollutants (NO, CO, and SO) from the power plant stack were measured The health effects and related costs were estimated by QUERI model from AirPacts according to the emissions, source and stack parameters, pollutant depletion velocities, exposure-response functions, local and regional population density, and detailed meteorological data. The results showed that the main health effect was assigned to the nitrate as restricted activity days (RAD) with 25,240 days/year. For all pollutants, the maximum health damage costs were related to the long-term mortality (49 %), restricted activity days (27 %), and chronic bronchitis (21 %). The annual health damage costs were approximately 4.76 million US$, with the cost being 0.096 US per kWh of generating electricity. Although the health damage costs of gas-fired power plant were lower than those of other heavy fuels, it seems essential to consider the health and environmental damages and focus on the emission control strategies, particularly in site selection for the new power plants and expanding the current ones.	https://pubmed.ncbi.nlm.nih.gov/27488708/	Yes
Gao B, Wang XM, Zhao XY, Ding X, Fu XX, Zhang YL, He QF, Zhang Z, Liu TY, Huang ZZ, Chen LG, Peng Y, Guo H. 2015. Source apportionment of atmospheric PAHs and their toxicity using PMF: Impact of gas/particle partitioning. Atmospheric Environment 103: 114-120.	24-h PM 2.5 samples were simultaneously collected at six sites in a subtropical city of South China during November–December, 2009. Particle-phase concentrations of polycyclic aromatic hydrocarbons (PAHs) and organic tracers such as hopanes for vehicular emissions (VE), levoglucosan for biomass burning (BB) and picene for coal combustion (CC) were determined. Meanwhile, their gas-phase concentrations were calculated from gas/particle (G/P) partitioning theory using the particle-phase concentrations. The 4 ring PAHs (fluoranthene to chrysene) had lower particle-phase fractions (10%–79%) than other species. Estimated BaP eq and lifetime cancer risk for particle-only (P-only) vs gas + particle (G + P) data sets showed similar values, indicating PAHs with 5–7 rings dominated the carcinogenicity of PAHs. Positive Matrix Factorization (PMF) was applied on both P-only and G + P data sets to estimate the source contributions to PAHs and their toxicity. Three common sources were identified: VE, BB and CC, with CC as the most significant source for both particulate (58%) and total (G + P, 40%) PAHs. While CC exhibited consistent contributions to BaP eq for P-only (66%) vs G + P (62%) solutions, VE and BB contributions were under- and overestimated by 68% and 47%, respectively by the P-only solution, as compared to the G + P solution. The results provide an insight on the impact of G/P partitioning on the source apportionment of PAHs and their toxicity.	https://www.sciencedirect.com/science/article/abs/pii/S1352231014009546	Yes
Gao M, Beig G, Song S, Zhang H, Hu J, Ying Q, Liang F, Liu Y, Wang H, Lu X, Zhu T, Carmichael GR, Nielsen CP, McElroy MB. 2018. The impact of power generation emissions on ambient PM2.5 pollution and human health in China and India. Environment international 121 (Pt 1): 250-259.	Emissions from power plants in China and India contain a myriad of fine particulate matter (PM 2.5 , PM ≤ 2.5 μm in diameter) precursors, posing significant health risks among large, densely settled populations. Studies isolating the contributions of various source classes and geographic regions are limited in China and India, but such information could be helpful for policy makers attempting to identify efficient mitigation strategies. We quantified the impact of power generation emissions on annual mean PM 2.5 concentrations using the state-of-the-art atmospheric chemistry model WRF-Chem (Weather Research Forecasting model coupled with Chemistry) in China and India. Evaluations using nationwide surface measurements show the model performs reasonably well. We calculated province-specific annual changes in mortality and life expectancy due to power generation emissions generated PM 2.5 using the Integrated Exposure Response (IER) model, recently updated IER parameters from Global Burden of Disease (GBD) 2015, population data, and the World Health Organization (WHO) life tables for China and India. We estimate that 15 million (95% Confidence Interval (CI): 10 to 21 million) years of life lost can be avoided in China each year and 11 million (95% CI: 7 to 15 million) in India by eliminating power generation emissions. Priorities in upgrading existing power generating technologies should be given to Shandong, Henan, and Sichuan provinces in China, and Uttar Pradesh state in India due to their dominant contributions to the current	https://www.sciencedirect.com/science/article/pii/S0160412018313369	Yes
Guan WJ, Zheng XY, Chung KF, Zhong NS. 2016. Impact of air pollution on the burden of chronic respiratory diseases in China: time for urgent action. The Lancet 388 (10054): 1939-1951.	Summary In China, where air pollution has become a major threat to public health, public awareness of the detrimental effects of air pollution on respiratory health is increasing—particularly in relation to haze days. Air pollutant emission levels in China remain substantially higher than are those in developed countries. Moreover, industry, traffic, and household biomass combustion have become major sources of air pollutant emissions, with substantial spatial and temporal variations. In this Review, we focus on the major constituents of air pollutants and their impacts on chronic respiratory diseases. We highlight targets for interventions and recommendations for pollution reduction through industrial upgrading, vehicle and fuel renovation, improvements in public transportation, lowering of personal exposure, mitigation of the direct effects of air pollution through healthy city development, intervention at population-based level (systematic health education, intensive and individualised intervention, pre-emptive measures, and rehabilitation), and improvement in air quality. The implementation of a national environmental protection policy has become urgent.	https://pubmed.ncbi.nlm.nih.gov/27751401/#:~:text=Impact%20of%20air%20pollution%20on%20the%20burden%20of,health%20is%20increasing-particularly%20in%20relation%20to%20haze%20days.	Yes
Gune MM, Ma WL, Sampath S, Li W, Li YF, Udayashankar HN, Balakrishna K. 2019. Occurrence of polycyclic aromatic hydrocarbons (PAHs) in air and soil surrounding a coal-fired thermal power plant in the south-west coast of India. Environmental Science and Pollution Research 26 (22): 22772-22782.	This investigation focused on the potential sources of polycyclic aromatic hydrocarbons (PAHs) in different matrices and their temporal variations surrounding a coal-fired thermal power plant in India. Samples were collected in different seasons for 1 year. Gas chromatography-mass spectroscopy (GC-MS) was used to perform the measurement of 16 priority PAHs. Average PAH concentrations were ranged from 0.71 to 2.99 ng/m.sup.3 in air and 1.59--22.7 ng/g in soil respectively. High levels of PAHs were found in soil compared to air, which indicated deposition in soil. This could be because of the fallout of high-molecular-weight compounds. During the monsoons, PAH concentrations in the air were the lowest compared to the other seasons because of the dilution effect. Phenanthrene, fluoranthene, and pyrenes were dominant in the air, contributing up to 32.5%, 22.7%, and 19.2% of total PAHs, respectively. On the other hand, soils contained fluoranthene (12.3%), pyrene (10.7%), benzo[b]fluoranthene (10%), chrysene (9.82%), and indeno[123-c,d]pyrene (9.64%) compounds. The occurrence of indeno[1,2,3-cd]pyrene (9.14 ng/g) indicated that the soil is contaminated from fly ash and diesel emissions from the thermal power plant and vehicular emission. The diagnostic ratios, thematic maps, and principal component analysis revealed that the fly ash, diesel emissions from the thermal power plant, vehicles, and biomass burning were the probable sources of PAHs in the study area. The human health risk assessment studies reveal that the soil samples are more prone to carcinogenicity than air samples. As per our knowledge, this is the first report on the impact of PAHs on air and soil in this region.	https://link.springer.com/article/10.1007%2Fs11356-019-05380-y	Yes

Reference	Abstract	URL	Peer Reviewed (Yes/No)
Guo L, Hu J, Xing Y, Wang H, Miao S, Meng Q, Wang X, Bai S, Jia J, Wang P, Zhang R, Gao P. 2020. Sources, environmental levels, and health risks of PM 2.5-bound polycyclic aromatic hydrocarbons in energy-producing cities in northern China. Environmental pollution (Barking, Essex : 1987) 272: 116024.	We collected 170 samples of airborne fine particulate matter from five coal-producing cities and one oil-producing city in northern China during both heating and non-heating periods to quantify the concentrations of 12 polycyclic aromatic hydrocarbons, estimate their bioaccessible fraction, and calculate the incremental lifetime cancer risk (ILCR) of this fraction. The major sources of the particulate matter were analyzed using the chemical mass balance model. We found that the main emission sources were coal combustion during the heating period and open sources during the non-heating period. The ILCR was initially calculated as 2.65 × 10 -9 for coal-producing cities and 4.60 × 10 -9 for the oil-producing city during the heating period and 1.17 × 10 -8 and 3.34 × 10 -8 , respectively, during the non-heating period. When only the bioaccessible fraction was used, the ILCR in coal-producing cities and the oil-producing city decreased by 87.2% and 82.1%, respectively, for the heating period and by 89.0% and 80.1%, respectively, for the non-heating period. The findings suggest that bioaccessibility should be considered when assessing the carcinogenic risk of polycyclic aromatic hydrocarbons. This study provides insights into the contribution of major emission sources to air pollution related to the long-term exploitation, transportation, and use of coal and oil.	https://www.sciencedirect.com/science/article/abs/pii/S0269749120367130?via%3Dihub	Yes
Liu J, Chen Y, Chao S, Cao H, Zhang A, Yang Y. 2018. Emission control priority of PM2.5-bound heavy metals in different seasons: A comprehensive analysis from health risk perspective. The Science of the Total Environment 644: 20-30.	Source-specific health risks of PM.sub.2.5-bound metals were analyzed for emission control by integrating source apportionment with health risk assessments of residents affected via inhalation pathways. A total of 218 daily PM.sub.2.5 samples were collected in 2016 in the central urban district of Beijing, China. Analyses showed that the mean annual concentrations of total heavy metals (THMs) and PM.sub.2.5 were 0.39 and 104.37 [mu]g m.sup.-3, respectively. The heating season had significantly higher concentrations of THMs and PM.sub.2.5 (0.61, 134 [mu]g m.sup.-3) than the non-heating season (0.27, 88.1 [mu]g m.sup.-3) (p < 0.05). Among all metals, arsenic had the largest incremental cancer risk of 7.04 x 10.sup.-6. Six sources were identified by positive matrix factorization combined with conditional probability function and potential source contribution function analyses. The order of contribution to PM.sub.2.5-bound metal concentrations was resuspended dust (61.0%), traffic emission (16.3%), Cu-related industry (14.1%), coal combustion (3.7%), Cr-related industry (3.4%), and fuel oil combustion (1.6%). During the heating season, the contribution of coal combustion decreased slightly, which may have been due to the countermeasure of substituting coal for gas or electric heat in 2016. However, in terms of cancer risk contribution, coal combustion was the top contributor in both heating (3.5 x 10.sup.-6, 51.6%) and non-heating (2.7 x 10.sup.-6, 59.6%) seasons due to high attributable contents of the toxic metals, As, Cd and Pb. The Cr-related and Cu-related industries were the next controlled sources in the heating and non-heating seasons, respectively. Thus, these sources should receive priority in the development of control measures.	https://www.sciencedirect.com/science/article/abs/pii/S0048969718323027	Yes
Lu M, Lin BL, Inoue K, Lei Z, Zhang X, Tsunemi K. 2018. PM2.5-related health impacts of utilizing ammonia-hydrogen energy in Kanto Region, Japan. Frontiers of Environmental Science & Engineering in China 12 (2): 1.	Ammonia has emerged as a promising hydrogen carrier with applications as an energy source in recent years. However, in addition to being toxic, gaseous ammonia is a precursor of secondary inorganic aerosols. The concentration of ambient fine particulate matter (PM.sub.2.5) is intrinsically connected to public health. In this study, PM.sub.2.5-related health impacts of utilizing ammonia-hydrogen energy in Kanto Region, Japan, were investigated. It was assumed that 20% of the electricity consumption in Kanto Region, the most populated area in Japan, was supplied by ammonia-hydrogen energy. The PM.sub.2.5 resulted from incomplete ammonia decomposition was simulated by a chemical transport model: ADMER-PRO (modified version). Based on the incremental PM.sub.2.5 concentration, health impacts on the elderly (individuals over 65 years old) were quantitatively evaluated. The ammonia emission in this scenario increased PM.sub.2.5 by 11.7% (0.16 [micro]g*m.sup.--3*y.sup.--1) in winter and 3.5% (0.08 [micro]g *m.sup.--3*y.sup.--1) in summer, resulting in 351 premature deaths per year. This study suggests that costeffective emissions control or treatment and appropriate land planning should be considered to reduce the associated health impacts of this type of energy generation. In addition, further in-depth research, including cost-benefit analysis and security standards, is needed.	https://link.springer.com/article/10.1007/s11783-018-1005-3#citeas	Yes
Malgorzata M, Zorena K, Waz P, Bartoszewicz M, Brandt-Varma A, Slezak D, Robakowska M. 2020. Gaseous pollutants and particulate matter (PM) in ambient air and the number of new cases of Type 1 diabetes in children and adolescents in the Pomeranian Voivodeship, Poland. BioMed Research International 2020: 1-7.	The increase in type 1 diabetes mellitus (T1DM) incidence in children is worrying and not yet fully explored. It is suggested that probably air pollution exposure could contribute to the development of T1DM. The aim of the study was to investigate the relationship between the concentration of gaseous pollutants including, nitrogen dioxide (NO2), nitric oxides (NOx), sulphur dioxide (SO2), carbon monoxide (CO), and particulate matter (PM) in the air, and the number of new cases of T1DM in children. The number of new cases of T1DM was obtained from the Clinic of Paediatrics, Diabetology, and Endocrinology, Medical University of Gdansk. The number of children of 0-18 years old in Pomeranian Voivodeship was acquired from the Statistical Yearbook. The concentrations of PM10 absorbance, NO2, NOx, SO2, and CO were measured at 41 measuring posts, between 1 January 2015 and 31 December 2016. It was detected that the average annual concentration of PM10 was higher than the value acceptable to the WHO. Furthermore, the average 24-hour concentration of PM10 was 92 ug/m3 and was higher compared to the acceptable value of 50 ug/m3 (acc. to EU and WHO). Moreover, the number of new cases of T1DM showed a correlation with the annual average concentration of PM10 (B = 2.396, p < 0.001), SO2 (B = 2.294, p < 0.001), and CO (B = 2.452, p < 0.001). High exposure to gaseous pollutants and particulate matter in ambient air may be one of the factors contributing to the risk of developing T1DM in children. Therefore, it is important to take action to decrease air pollutant emissions in Poland. It is crucial to gradually but consistently eliminate the use of solid fuels, such as coal and wood in households, in favour of natural gas and electricity. The development of new technologies to improve air quality, such as 'best available techniques' (BAT) or renewable energy sources (water, wind, and solar generation) is of critical importance as	https://pubmed.ncbi.nlm.nih.gov/32099842/	Yes
Muyemeki L, Burger R, Piketh SJ, Evans SW. 2017. Bird species richness and densities in relation to sulphur dioxide gradients and environmental variables. Ostrich: The Journal of African Ornithology 88 (3): 253-259.	The expansion of coal-fired power stations in South Africa has resulted in growing environmental concerns as they are the largest emitters of sulphur dioxide (SO2). Sulphur dioxide emissions from power plants pose a potential threat to avian populations. However, the effect of SO2pollution on bird communities is poorly understood. Using point counts we investigated the relationships of bird species richness and species-specific density with SO2concentrations around Matimba power station. Environmental parameters were derived from remotely sensed data and data reduction was performed using principal component analysis. Generalised linear mixed models were then used to infer the relationships of bird species richness and species-specific densities with SO2concentrations and the environmental variables. Our results revealed that SO2-polluted air had no influence on bird species richness and densities in our study sites, but SO2levels were below annual national ambient air quality standards. Vegetation productivity was found to have a greater influence on species densities than SO2pollution. Monitoring of bird population changes around Matimba power station once neighbouring Medupi power station is fully operational is recommended, as SO2content of the air will increase significantly, and species may be sensitive to this increase in SO2levels.	https://www.tandfonline.com/doi/abs/10.2989/00306525.2017.1310144	Yes
Peng H, Wang BF, Yang FL, Cheng FQ. 2020. Study on the environmental effects of heavy metals in coal gangue and coal combustion by ReCiPe2016 for life cycle impact assessment. Journal of Fuel Chemistry and Technology 48 (11): 1402-1408.	During coal and coal gangue combustion, many heavy metal pollutants are emitted and cause serious environmental problems. In this paper, the environmental effect values of As and Pb emission during coal gangue and coal combustion in the 330 MW pulverized coal boiler, 50 kW circulated fluidized bed boiler and laboratory were calculated by ReCiPe2016. The results show that when coal combustion in 330 MW pulverized coal boiler, the environment effect values of as for bottom slag, fly ash and flue gas are 3.28×10 −6, 2.68×10−5 and 3.89×10−3 respectively; while the environment effect value of Pb for bottom slag, fly ash and flue gas are 8.57×10 −6, 6.00×10−5 and 4.83×10−2, respectively. The environmental effects of As and Pb in bottom slag are lower than those in the fly ash; and the environmental effects of As and Pb on air are higher than those on soil. Moreover, when coal combustion in the 50 kW circulated fluidized boiler, the effect values of As and Pb in fly ash on environment are 3.26×10 −5 and 1.28×10−4; and the effect values of As and Pb in bottom slag are 1.16×10−6 and 1.43×10−5 respectively. The results also show that when coal gangue combustion in the laboratory, the effect values of As and Pb emission increase with increasing of the temperature; and the proportions of total environmental effects of As and Pb on air are higher than those on soil. Besides that, this study also indicates that the effect of Pb emitted into environment is higher than that of As at the same conditions during coal combustion both in circulated fluidized boiler and pulverized coal boiler. The results may provide basic data for predicting the environmental effects of As and Pb during coal gangue combustion in circulating fluidized bed for life cycle impact assessment.	https://www.sciencedirect.com/science/article/abs/pii/S1872581320300906	Yes
Pizzol M, Møller F, Thomsen M. 2013. External costs of atmospheric lead emissions from a waste-to-energy plant: A follow-up assessment of indirect exposure via topsoil ingestion. Journal of Environmental Management 121: 170-178.	In this study the Impact Pathway Approach (IPA) was used to calculate the external costs associated with indirect exposure, via topsoil ingestion, to atmospheric emissions of lead (Pb) from a waste-to-energy plant in Denmark. Three metal-specific models were combined to quantify the atmospheric dispersion of lead, its deposition and accumulation in topsoil, and the increase in blood lead concentration for children resulting from lead intake via topsoil ingestion. The neurotoxic impact of lead on children was estimated using a lead-specific concentration-response function that measures impaired cognitive development in terms of IQ points lost per each incremental μg/dl of lead in blood. Since IQ loss during childhood can be associated with a percent decrease in expected lifetime earnings, the monetary value of such an impact can be quantified and the external costs per kg of lead emitted from the plant were then calculated. The costs of indirect exposure calculated over a time horizon of 100 years, for the sub-population of children of 0–3 years, and discounted at 3%, were in the range of 15–30 €/kg. Despite the continued accumulation of lead in topsoil resulting in increasing future indirect exposure, the results indicate that costs associated with this exposure pathway are of the same order of magnitude as costs associated with direct exposure via inhalation, calculated at 45–91 €/kg. Moreover, when the monetary value of future impacts is discounted to the present, the differences between the two exposure pathways are diminished. Finally, setting a short time horizon reduces the uncertainties but excludes part of the costs of indirect exposure from the assessment.	https://www.sciencedirect.com/science/article/pii/S030147971300131X	Yes
Popadić D, Heßelbach K, Richter-Brockmann S, Kim GJ, Flemming S, Schmidt-Heck W, Häupl T, Bonin M, Dornhof R, Achten C, Günther S, Humar M, Merfort I. 2018. Gene expression profiling of human bronchial epithelial cells exposed to fine particulate matter (PM2.5) from biomass combustion. Toxicology & Applied Pharmacology 347: 10-22.	One-third of the world's population relies on solid biomass fuels for domestic energy demands. In contrast to industrial or traffic related emissions, only a limited number of studies focus on the adverse health effects of particulate matter (PM) from biomass combustion. We conducted Affymetrix Human Genome U133 Plus 2.0 arrays, bioinformatic analysis, qRT-PCR and immunoblotting to determine the molecular impact of fuelwood-derived PM 2.5 on lung epithelial BEAS-2B cells. In the presence of PM 2.5 175 differentially regulated genes were identified. Gene ontology (GO), pathway and functional enrichment analysis allocated these genes to cellular development, metabolism, inflammation, cancer and the immune system. Analysis of enriched transcription factor binding sites extracted 15 PM 2.5 responsive transcription factors, including the polycyclic aromatic hydrocarbon (PAH)-activated aryl hydrocarbon receptor (AhR). Accordingly, a complex mixture of PAHs was detected in the PM 2.5 fraction using APLI and AhR-inhibitors reduced the up-regulation of CYP1A1 , EREG , GREM1 , IL1B and IL6 , indicating that PAHs are involved in PM 2.5 specific gene deregulation. We also provide evidence, that HIF-1α might be responsive to PM 2.5 . To analyze the impact of microbial infections, PM 2.5 predisposed cells were incubated with LPS or dsRNA. We identified 40 LPS and 380 dsRNA specific genes in PM 2.5 predisposed cells. GO allocated these genes with chemokine dependent and inflammatory pathways, viral responses and xenobiotic metabolism. A disease ontology allocated lung and lung associated diseases to PM 2.5 exposed cells. In some cases LPS or dsRNA increased significance of probability of diseases. Altogether our studies enhance our knowledge on the mechanism	https://www.sciencedirect.com/science/article/abs/pii/S0041008X18301108	Yes
Requia W J, Adams MD, Koutrakis P. 2017. Association of PM2.5 with diabetes, asthma, and high blood pressure incidence in Canada: A spatiotemporal analysis of the impacts of the energy generation and fuel sales. Science of the Total Environment 584-585: 1077-1083.	Numerous studies have reported an association between fine particulate matter (PM2.5) and human health. Often these relationships are influenced by environmental factor that varies spatially and/or temporally. To our knowledge, there are no studies in Canada that have considered energy generation and fuel sales as PM2.5 effects modifiers. Determining exposure and disease-specific risk factors over space and time is crucial for disease prevention and control. In this study, we evaluated the association of PM2.5 with diabetes, asthma, and High Blood Pressure (HBP) incidence in Canada. Then we explored the impact of the energy generation and fuel sales on association changes. We fit an age-period-cohort as the study design, and we applied an over-dispersed Poisson regression model to estimate the risk. We conducted a sensitivity analysis to explore the impact of variation in clean energy rates and fuel sales on outcomes changes. The study included 117 health regions in Canada between 2007 and 2014. Our findings showed strong association of PM2.5 with diabetes, asthma, and HBP incidence. A two-year increase of 10μg/m3 in PM2.5 was associated with an increased risk of 5.34% (95% CI: 2.28%; 12.53%) in diabetes incidence, 2.24% (95% CI: 0.93%; 5.38%) in asthma incidence, and 8.29% (95% CI: 3.44%; 19.98%) in HBP incidence. Our sensitivity analysis findings suggest higher risks of diabetes, asthma and HBP incidence when there is low clean energy generation. On the other hand, we found lower risk when we considered high rate of clean energy generation. For example, considering only diabetes incidence, we found that the risk in health regions with low rates of clean electricity is approximately 700% higher than the risk in health regions with high rates of clean electricity. Furthermore, our analysis suggested that the risk in regions with low fuel sales is 66% lower than the risk is health regions with low rates of clean electricity. Our study provides support for the creation of effective environmental health public policies that take into account the risk factors present in Canadians health regions.	https://www.sciencedirect.com/science/article/abs/pii/S0048969717301833	Yes
Sarkar S, Khillare PS. 2013. Profile of PAHs in the inhalable particulate fraction: source apportionment and associated health risks in a tropical megacity. Environmental monitoring and assessment 185 (2): 1199-1213.	The present study proposed to investigate the atmospheric distribution, sources, and inhalation health risks of polycyclic aromatic hydrocarbons (PAHs) in a tropical megacity (Delhi, India). To this end, 16 US EPA priority PAHs were measured in the inhalable fraction of atmospheric particles (PM(10); aerodynamic diameter, ≤ 10 μm) collected weekly at three residential areas in Delhi from December 2008 to November 2009. Mean annual 24 h PM(10) levels at the sites (166.5-192.3 μg m(-3)) were eight to ten times the WHO limit. Weekday/weekend effects on PM(10) and associated PAHs were investigated. Σ(16)PAH concentrations (sum of 16 PAHs analyzed; overall annual mean, 105.3 ng m(-3); overall range, 10.5-511.9 ng m(-3)) observed were at least an order of magnitude greater than values reported from European and US cities. Spatial variations in PAHs were influenced by nearness to traffic and thermal power plants while seasonal variation trends showed highest concentrations in winter. Associations between Σ(16)PAHs and various meteorological parameters were investigated. The overall PAH profile was dominated by combustion-derived large-ring species (85-87 %) that were essentially local in origin. Carcinogenic PAHs contributed 58-62 % to Σ(16)PAH loads at the sites. Molecular diagnostic ratios were used for preliminary assessment of PAH sources. Principal component analysis coupled with multiple linear regression-identified vehicular emissions as the predominant source (62-83 %), followed by coal combustion (18-19 %), residential fuel use (19 %), and industrial emissions (16 %). Spatio-temporal variations and time-evolution of source contributions were studied. Inhalation cancer risk assessment showed that a maximum of 39,780 excess cancer cases might occur due to lifetime	https://pubmed.ncbi.nlm.nih.gov/22527461/	Yes

Reference	Abstract	URL	Peer Reviewed (Yes/No)
Sears CG, Sears L, Zierold KM. 2020. Sex differences in the association between exposure to indoor particulate matter and cognitive control among children (age 6–14 years) living near coal-fired power plants. Neurotoxicology & Teratology 78: 106855.	Coal fly ash consists of inhalable particulate matter with varying concentrations of neurotoxic metals. Children living near coal-fired power plants with coal fly ash storage facilities may be exposed to coal fly ash when it escapes as fugitive dust emissions into surrounding communities. Previous research on outdoor particulate matter air pollution of similar aerodynamic diameter (PM 10) suggests exposure may be associated with impaired cognitive control. The purpose of this research was to investigate sex-differences in the association between exposure to indoor PM 10 and cognitive control among children (n = 221), ages 6–14 years, living near coal-fired power plants with fly ash storage facilities. In an ongoing community-based study, we measured indoor PM 10 concentrations in participants' housing units and used performance measures from the BARS (Behavior Assessment and Research System) Continuous Performance Test (CPT) and Selective Attention Test (SAT) to assess neurotoxic effects on cognitive control. In adjusted negative binomial regression models, we found children living in housing units with higher indoor PM 10 concentrations had a higher risk of commission errors on the CPT (incidence rate ratio (IRR) = 1.22 per interquartile range difference (IQR = 0.72 µg/m3) in natural log-transformed PM 10 concentrations; 95% CI = 1.01, 1.46) and SAT (IRR = 1.14; 95% CI = 1.01, 1.28). Furthermore, child sex modified the association between PM 10 concentration and CPT commission errors. Among females, higher PM 10 concentration was associated with higher risk of CPT commission errors (IRR = 1.39; 95% CI = 1.06, 1.82), but we found no association among males (IRR = 1.01; 95% CI = 0.79, 1.30). We found no association between PM 10 concentrations and CPT or SAT response latency. Our results suggest females living near coal-fired plants with coal fly ash storage facilities may be more susceptible to impaired cognitive control associated with particulate matter exposure. Children living near coal-fired power plants with coal fly ash storage facilities who are exposed to particulate matter may have an increased risk of impulse control problems. • The association between indoor PM 10 concentrations and children's performance on two tests of cognitive control was assessed. • Higher PM 10 concentrations were associated with higher risk of commission errors on tests of cognitive control. • Females may be more susceptible to impulsivity associated with PM 10 exposure.	https://www.sciencedirect.com/science/article/abs/pii/S089203621930128X	Yes
Shepherd MA, Haynatzki G, Rautiainen R, Achutan C. 2015. Estimates of community exposure and health risk to sulfur dioxide from power plant emissions using short-term mobile and stationary ambient air monitoring. Journal of the Air & Waste Management Association (Taylor & Francis Ltd) 65 (10): 1239-1246.	To estimate plausible health effects associated with peak sulfur dioxide (SO2) levels from three coal-fired power plants in the Baltimore, Maryland, area, air monitoring was conducted between June and September 2013. Historically, the summer months are periods when emissions are highest. Monitoring included a 5-day mobile and a subsequent 61-day stationary monitoring study. In the stationary monitoring study, equipment was set up at four sites where models predicted and mobile monitoring data measured the highest average concentrations of SO2. Continuous monitors recorded ambient concentrations each minute. The 1-min data were used to calculate 5-min and 1-hr moving averages for comparison with concentrations from clinical studies that elicited lung function decrement and respiratory symptoms among asthmatics. Maximum daily 5-min moving average concentrations from the mobile monitoring study ranged from 70 to 84 ppb (183–220 µg/m3), and maximum daily 1-hr moving average concentrations from the mobile monitoring study ranged from 15 to 24 ppb (39–63 µg/m3). Maximum 5-min moving average concentrations from stationary monitoring ranged from 39 to 229 ppb (102–600 µg/m3), and maximum daily 1-hr average concentrations ranged from 15 to 134 ppb (40–351 µg/m3). Estimated exposure concentrations measured in the vicinity of monitors were below the lowest levels that have demonstrated respiratory symptoms in human clinical studies for healthy exercising asthmatics. Based on 5-min and 1-hr monitoring, the exposure levels of SO2in the vicinity of the C.P. Crane, Brandon Shores, and H.A. Wagner power plants were not likely to elicit respiratory symptoms in healthy asthmatics. Implications:Mobile and stationary air monitoring for SO2 were conducted to quantify short-term exposure risk, to the surrounding community, from peak emissions of three coal-fired power plants in the Baltimore area. Concentrations were typically low, with only a few 5-min averages higher than levels indicated during clinical trials to induce changes in lung capacity for healthy asthmatics engaged in exercise outdoors.	https://www.tandfonline.com/doi/full/10.1080/10962247.2015.1077174	Yes
Thongthammachart T, Pimkotr K, Jinsart W. 2017. Health risk assessment of nitrogen dioxide and sulfur dioxide exposure from a new developing coal power plant in Thailand. EnvironmentAsia 10 (2): 186-194.	Krabi coal-fired power plant is the new power plant development project of the Electricity Generating Authority of Thailand (EGAT). This 800 megawatts power plant is in developing process. The pollutants from coal-fired burning emissions were estimated and included in an environmental impact assessment report. This study aims to apply air quality modeling to predict nitrogen dioxide (NO2) and sulfur dioxide (SO2) concentration which could have health impact to local people. The health risk assessment was studied following U.S. EPA regulatory method. The hazard maps were created by ArcGIS program. The results indicated the influence of the northeast and southwest monsoons and season variation to the pollutants dispersion. The daily average and annual average concentrations of NO2 and SO2 were lower than the NAAQS standard. The hazard quotient (HQ) of SO2 and NO2 both short-term and long-term exposure were less than 1. However, there were some possibly potential risk areas indicating in GIS based map. The distribution of pollutions and high HI values were near this power plant site. Although the power plant does not construct yet but the environment health risk assessment was evaluated to compare with future fully developed coal fire plant.	https://www.researchgate.net/publication/318786247_Health_risk_assessment_of_nitrogen_dioxide_and_sulfur_dioxide_exposure_from_a_new_developing_coal_power_plant_in_Thailand	Yes
Tian K, Bao H, Zhang X, Shi T, Liu X, Wu F. 2018. Residuals, bioaccessibility and health risk assessment of PAHs in winter wheat grains from areas influenced by coal combustion in China. Science of the Total Environment 618: 777-784.	Polycyclic aromatic hydrocarbons (PAHs) contamination in atmospheric and soil was serious, which is mainly due to high level of emission of PAHs in China resulted from the predominating use of coal in energy consumption and continuous development of economy and society for years. However, the status of PAHs in winter wheat grains from the areas influenced by coal combustion in China was still not clear. During harvest season, the winter wheat grains were collected from agricultural fields surrounding coal-fired power plants located in Shaanxi and Henan Provinces. This study found that the mean concentrations of 15 priority PAHs ranged from 69.58 to 557.0 µg kg − 1 . Three-ring PAHs (acenaphthene, acenaphthylene, fluorene, phenanthrene and anthracene) were dominant in the grains, accounting for approximately 70–81% of the total PAHs. The bioaccessibility of low molecular weight (LMW, 2–3 ring) PAHs (51.1–52.8%), high molecular weight (HMW, 4–6 ring) PAHs (19.8–27.6%) and total PAHs (40.9–48.0%) in the intestinal condition was significantly (p < 0.001) higher than that (37.4–38.6%; 15.6–22.5%; 30.7–35.5%) in the gastric condition, respectively. Based on total PAHs, the values of incremental lifetime cancer risk (ILCR) for children, adolescents, adults and seniors were all higher than the baseline value (10 − 6) and some even fell in the range of 10 − 5 –10 − 4 , which indicated that most grains from the areas affected by coal combustion possessed considerable cancer risk. The present study also indicated that the children were the age group most sensitive to PAHs contamination. The pilot research provided relevant information for the regulation of PAHs in the winter wheat grains and for the safety of the agro-products growing in the PAHs-contaminated areas.	https://www.sciencedirect.com/science/article/abs/pii/S0048969717321721	Yes
Wang K, Wang W, Li L, Li J, Wei L, Chi W, Hong L, Zhao Q, Jiang J. 2020. Seasonal concentration distribution of PM1.0 and PM2.5 and a risk assessment of bound trace metals in Harbin, China: Effect of the species distribution of heavy metals and heat supply. Scientific Reports 10 (1): 8160.	To clarify the potential carcinogenic/noncarcinogenic risk posed by particulate matter (PM) in Harbin, a city in China with the typical heat supply, the concentrations of PM1.0 and PM2.5 were analyzed from Nov. 2014 to Nov. 2015, and the compositions of heavy metals and water-soluble ions (WSIs) were determined. The continuous heat supply from October to April led to serious air pollution in Harbin, thus leading to a significant increase in particle numbers (especially for PM1.0). Specifically, coal combustion under heat supply conditions led to significant emissions of PM1.0 and PM2.5, especially heavy metals and secondary atmospheric pollutants, including SO42 −, NO3−, and NH4+. Natural occurrences such as dust storms in April and May, as well as straw combustion in October, also contributed to the increase in WSIs and heavy metals. The exposure risk assessment results demonstrated that Zn was the main contributor to the average daily dose through ingestion and inhalation, ADDIng and ADDinh, respectively, among the 8 heavy metals, accounting for 51.7–52.5% of the ADDIng values and 52.5% of the ADDinh values. The contribution of Zn was followed by those of Pb, Cr, Cu and Mn, while those of Ni, Cd, and Co were quite low (<2.2%).	https://pubmed.ncbi.nlm.nih.gov/32424213/	Yes
Wang Q, Dong Z, Guo Y, Yu F, Zhang Z, Zhang R. 2020. Characterization of PM 2.5-bound polycyclic aromatic hydrocarbons at two central China cities: Seasonal variation, sources, and health risk assessment. Archives of environmental contamination and toxicology 78 (1): 20-33.	In this study, ambient PM 2.5 samples were collected from October 2014 to August 2015 in urban area of Luoyang (LY) and Pingdingshan (PDS), two medium-size industrial cities in central China. Sixteen priority polycyclic aromatic hydrocarbons (PAHs) were analyzed to investigate the seasonal variation, potential pollution sources, and health risk of PAHs bound to PM 2.5 (PM 2.5 -bound PAHs). The diagnostic ratios analysis and positive matrix fraction (PMF) model were used to identify potential sources of PM 2.5 -bound PAHs. The annual average concentrations of PM 2.5 and PM 2.5 -bound PAHs were 128 µg m -3 and 73 ng m -3 for LY, and 119 µg m -3 and 182 ng m -3 for PDS, respectively, both displaying seasonal trends with higher concentrations in winter and autumn than in spring and summer. BaP equivalent concentrations were 14.4 and 16.5 ng m -3 in LY and PDS, respectively. The predominant PAHs were 4-6 ring PAHs, with contribution of more than 80% at both sampling sites. PMF analysis revealed that coal combustion was the most important source of PM 2.5 -bound PAHs in LY and PDS, accounting for 37% and 39%, respectively, followed by traffic emissions (34% and 33% in LY and PDS,	https://link.springer.com/article/10.1007/s00244-019-00671-4	Yes
Wang R, Liu G, Zhang J. 2015. Variations of emission characterization of PAHs emitted from different utility boilers of coal-fired power plants and risk assessment related to atmospheric PAHs. Science of the Total Environment 538: 180-190.	Coal-fired power plants (CFPPs) represent important source of atmospheric PAHs, however, their emission characterization are still largely unknown. In this work, the concentration, distribution and gas-particle partitioning of PM 10 - and gas-phase PAHs in flue gas emitted from different coal-fired utility boilers were investigated. Moreover, concentration and distribution in airborne PAHs from different functional areas of power plants were studied. People's inhalatory and dermal exposures to airborne PAHs at these sites were estimated and their resultant lung cancer and skin cancer risks were assessed. Results indicated that the boiler capacity and operation conditions have significant effect on PAH concentrations in both PM 10 and gas phases due to the variation of combustion efficiency, whereas they take neglected effect on PAH distributions. The wet flue gas desulphurization (WFGD) takes significant effect on the scavenging of PAH in both PM 10 and gas phases, higher scavenging efficiency were found for less volatile PAHs. PAH partitioning is dominated by absorption into organic matter and accompanied by adsorption onto PM 10 surface. In addition, different partitioning mechanism is observed for individual	https://www.sciencedirect.com/science/article/abs/pii/S0048969715305465	Yes
Wang XT, Miao Y, Zhang Y, Li YC, Wu MH, Yu G. 2013. Polycyclic aromatic hydrocarbons (PAHs) in urban soils of the megacity Shanghai: Occurrence, source apportionment and potential human health risk. The Science of the Total Environment 447: 80-89.	A comprehensive investigation was conducted to the urban soil in the megacity Shanghai in order to assess the levels of PAHs and potential risks to human health, to identify and quantitatively assess source contributions to the soil PAHs. A total of 57 soil samples collected in main urban areas of Shanghai, China were analyzed for 26 PAHs including highly carcinogenic dibenzopyrene isomers. The total concentrations ranged from 133 to 8650ngg-1 for Σ26PAHs and 83.3 to 7220ngg-1 for Σ16PAHs, with mean values of 2420 and 1970ngg-1, respectively. DBalP and DBaeP may serve as markers for diesel vehicle emission, while DBahP is a probable marker of coke tar as distinct from diesel emissions. Six sources in Shanghai urban area were identified by PMF model; their relative contributions to the total soil PAH burden were 6% for petrogenic sources, 21% for coal combustion, 13% for biomass burning, 16% for creosote, 23% for coke tar related sources and 21% for vehicular emissions, respectively. The benzo[a]pyrene equivalent (BaP.sub.eq) concentrations ranged from 48.9-2580ngg-1 for Σ24PAHs, 7.02-869ngg-1 for U276PAHs and 35.7-1990ngg-1 for Σ4DBPs. The BaPeq concentrations of Σ4DBPs made up 72% of Σ24PAHs. Nearly half of the soil samples showed concentrations above the safe BaP.sub.eq value of 600ngg-1. Exposure to these soils through direct contact probably poses a significant risk to human health from	https://www.sciencedirect.com/science/article/abs/pii/S0048969712016439	Yes

Reference	Abstract	URL	Peer Reviewed (Yes/No)
Xu H, Ho SSH, Gao M, Cao J, Guinot B, Ho KF, Long X, Wang J, Shen Z, Liu S, Zheng C, Zhang Q. 2016. Microscale spatial distribution and health assessment of PM2.5-bound polycyclic aromatic hydrocarbons (PAHs) at nine communities in Xi'an, China. Environmental Pollution 218: 1065-1073.	Spatial variability of polycyclic aromatic hydrocarbons (PAHs) associated with fine particulate matter (PM2.5) was investigated in Xi'an, China, in summer of 2013. Sixteen priority PAHs were quantified in 24-h integrated air samples collected simultaneously at nine urban and suburban communities. The total quantified PAHs mass concentrations ranged from 32.4 to 104.7 ng m −3, with an average value of 57.1 ± 23.0 ng m−3. PAHs were observed higher concentrations at suburban communities (average: 86.3 ng m −3) than at urban ones (average: 48.8 ng m−3) due to a better enforcement of the pollution control policies at the urban scale, and meanwhile the disorganized management of motor vehicles and massive building constructions in the suburbs. Elevated PAH levels were observed in the industrialized regions (west and northwest of Xi'an) from Kriging interpolation analysis. Satellite-based visual interpretations of land use were also applied for the supporting the spatial distribution of PAHs among the communities. The average benzo[a]pyrene-equivalent toxicity (Σ[BaP]eq) at the nine communities was 6.9 ± 2.2 ng m −3 during the sampling period, showing a generally similar spatial distribution to PAHs levels. On average, the excess inhalation lifetime cancer risk derived from Σ[BaP]eq indicated that eight	https://www.sciencedirect.com/science/article/abs/pii/S026974911630968X	Yes
Xue Q, Jiang Z, Wang Z, Song D, Huang F, Tian Y, Huang-fu Y, Feng Y. 2019. Comparative study of PM10-bound heavy metals and PAHs during six years in a Chinese megacity: Compositions, sources, and source-specific risks. Ecotoxicology and Environmental Safety 186: 109740.	To comparatively analyze source-specific risks of atmospheric particulate matter (PM), PM10-bound polycyclic aromatic hydrocarbons (PAHs) and heavy metals (HMs) were synchronously detected in a megacity (Chengdu, China) from 2009 to 2016. Non-cancer risk (assessed by hazard quotient, HQ) of PAHs and HMs was within the acceptable level, while cancer risk (assessed by incremental life cancer risk (ILCR), R) of PAHs and HMs were 1.01 × 10 −4 and 9.40 × 10−5 in DP and WP, which showed low risk. HMs dominated cancer (92.12%) and non-cancer (99.99%) risks. An advanced method named as joint source-specific risk assessment of HMs and PAHs (HP-SRA model) was developed to assess comprehensive source-specific risks. Gasoline combustion (contributed 9.6% of PM10, 0.3% of HQ and 10.0% of R), diesel combustion (6.2% of PM10, 0.2% of HQ and 10.7% of R), coal combustion (17.5% of PM10, 1.8% of HQ and 13.4% of R), industrial source (9.1% of PM10, 80.7% of HQ and 35.0% of R), crustal dust (28.1% of PM10, 9.0% of HQ and 1.6% of R), nitrate (7.5% of PM10, 1.1% of HQ and 6.2% of R) and sulphate & secondary organic carbon & adsorption (SSA, 19.6% of PM10, 6.9% of HQ and 23.1% of R) were identified as main sources. For cancer risk, industrial sources and SSA posed the highest proportion. Higher levels of Co and Ni generated from industrial sources and Cr (Ⅵ), Cd and Ni absorbed in the SSA can result in high-risk contributions. Thus, controlling HMs levels in industrial emissions is essential to protecting human health.	https://www.sciencedirect.com/science/article/abs/pii/S0147651319310711?via%3Dihub	Yes
Yan D, Wu S, Zhou S, Tong G, Li F, Wang Y, Li B. 2019. Characteristics, sources and health risk assessment of airborne particulate PAHs in Chinese cities: A review. Environmental Pollution 248: 804-814.	Polycyclic aromatic hydrocarbons (PAHs) are organic compounds composed of at least two benzene rings. This paper reviews the characteristics, sources and health risk of airborne particulate PAHs in Chinese cities. The airborne particulate PAH concentrations varied from 3.35 to 910 ng m-3, with an average of 75.0 ng m+U32-3, and the pollution level of PAHs in northern cities was generally higher than that in southern cities. The PAH concentrations in different cities underwent similar seasonal variations, with high concentrations in the winter and relatively low concentrations in the summer. Many factors, such as meteorological conditions and source emissions, influenced the spatiotemporal pattern of PAHs. High temperatures, frequent flow exchanges, abundant rainfall and strong solar radiation reduced the level of particulate PAHs in the atmosphere. The historical changes in the level of airborne particulate PAHs in four cities were analyzed. The PAH concentrations in Beijing and Taiyuan presented a trend of first increasing and then decreasing, while the level of particulate PAHs in Nanjing and Guangzhou had a decreasing tendency from year 2000--2015. The airborne particulate PAHs in cities were derived from several sources, including coal combustion, vehicle emissions, coking industries, biomass burning and petroleum volatilization. The results of a health risk assessment indicated that the incremental lifetime cancer risk (ILCR) for people in the northern cities was higher than that for people in the other regions, especially during the cold season. Moreover, adults were at greater risk than people in other age groups, and the health risk to females was slightly higher than that to males. The potential risk of airborne particulate PAH exposure was relatively high in some cities, and controlling PAH emissions at the source should be required to prevent pollution.	https://www.sciencedirect.com/science/article/abs/pii/S0269749118352230	Yes
Yuan TH, Pien WH, Chan CC. 2013. Urinary heavy metal levels of residents in the vicinity of a petrochemical complex in Taiwan. E3S Web of Conferences 1: 21001.	A petrochemical complex located in central Taiwan is a major emission source of air pollutants locally. Among these air pollutants, it is concern that the health effects of exposure to heavy metal because of its toxicity and persistency. Therefore, we conducted a biological monitoring study to investigate the effect of heavy metal pollutants on inhabitants around this petrochemical complex. According to the distance and the wind direction from the petrochemical complex, the study area was divided into high exposure (HE) and low exposure (LE) areas, and a total of 673 study subjects who aged above 35 years old living in HE and LE areas were recruited to be collected urine sample and personal information by health screen and questionnaire administration. The concentrations of ten kinds of urinary heavy metals were analyzed by inductively coupled plasma mass spectrometry. After adjusting for age, gender, socioeconomic status, smoking, dietary habits and other potential confounders, the multiple linear regression models showed that the urinary levels of vanadium, manganese, arsenic and strontium of inhabitants in HE area were significantly higher than those of inhabitants in LE area. This study indicated the potential effects of emitted metal pollutants from a petrochemical complex on the residents nearby.	https://www.e3s-conferences.org/articles/e3sconf/pdf/2013/01/e3sconf_ichm13_21001.pdf	Yes
Zanobetti A, Austin E, Coull BA, Schwartz J, Koutrakis P. 2014. Health effects of multi-pollutant profiles. Environment International 71: 13-19.	The association between exposure to particle mass and mortality is well established; however, there are still uncertainties as to whether certain chemical components are more harmful than others. Moreover, understanding the health effects associated with exposure to pollutant mixtures may lead to new regulatory strategies. We applied a time series analysis to examine the association of PM2.5 with daily deaths. Subsequently, we included an interaction term between PM2.5 and the pollution mixture clusters. Results We found a 1.1% increase (95% CI: 0.0, 2.2) and 2.3% increase (95% CI: 0.9–3.7) in total mortality for a 10μg/m3 increase in the same day and the two-day average of PM2.5 respectively. The association is larger in a cluster characterized by high concentrations of the elements related to primary traffic pollution and oil combustion emissions with a 3.7% increase (95% CI: 0.4, 7.1) in total mortality, per 10μg/m3 increase in the same day average of PM2.5. Our study shows a higher association of PM2.5 on total mortality during days with a strong contribution of traffic emissions, and fuel oil combustion. Our proposed method to create multi-pollutant profiles is robust, and provides a promising tool to identify multi-pollutant mixtures which can be linked to the health effects.	https://www.sciencedirect.com/science/article/pii/S0160412014001731	Yes
Zha Y, Zhang YL, Tang J, Sun K. 2018. Status, sources, and human health risk assessment of PAHs via foliar dust from different functional areas in Nanjing, China. Journal of Environmental Science & Health, Part A: Toxic/Hazardous Substances & Environmental Engineering 53 (6): 571-582.	The present study was carried out to assess and understand the potential health risk, level of contamination, composition pattern, and sources of urban foliar dust in Nanjing City with respect to polycyclic aromatic hydrocarbons (PAHs). Five urban functional areas of foliar dust were analysed and the contents of 16 priority PAHs were determined. Total PAH concentrations in foliar dust ranged from 1.77 to 19.02 μg·g −1, with an average value of 6.98 μg·g−1. The PAH pattern was dominated by four and five-ring PAHs (contributing > 38% of total PAHs) in all of the five functional areas. The results indicated that the combustion of fossil fuel, coal, and biomass, as well as vehicle traffic emissions were the major sources of PAHs. The estimated incremental lifetime cancer risk due to PAHs in foliar dust were 8.19 × 10 −6, 6.63 × 10−6, and 9.65 × 10−6 for childhood, adolescence and adulthood, respectively, indicating a high risk of cancer from exposure to foliar dust in Nanjing. Our results indicated that foliar dust might be a useful indicator of atmospheric PAH pollution.	https://www.tandfonline.com/doi/abs/10.1080/10934529.2018.1428267	Yes
Zhang L, Xu H, Fang B, Wang H, Yang Z, Yang W, Hao Y, Wang X, Wang Q, Wang M. 2020. Source identification and health risk assessment of polycyclic aromatic hydrocarbon-enriched PM2.5 in Tangshan, China. Environmental toxicology and chemistry 39 (2): 458-467.	Tangshan city in Hebei Province is one of the most heavily polluted cities in China, with substantial industrial emissions. The development of effective air pollution emission reduction policies requires knowledge of the sources and health risks of polycyclic aromatic hydrocarbon (PAH)-enriched fine particulate matter (PM 2.5). We investigated the seasonal variation and source apportionment of 16 priority PAH-enriched PM 2.5 samples in Tangshan during 2014 and 2015, and we assessed the health risks associated with inhalation exposure to PAHs. The PM 2.5 samples were collected from April 2014 to February 2015. We analyzed the concentrations of PM 2.5 and PAH-enriched PM 2.5 , and used principal component analysis and molecular diagnostic ratios to identify potential sources. We explored the relationship between distribution and meteorological conditions, and used an incremental lifetime cancer risk (ILCR) model to quantitatively evaluate exposure from the inhalation risk of PAHs. The average mass concentration of PM 2.5 was 196 μg/m 3 , with a range 34.0 to 586 μg/m 3 . The median ∑16 PAH values in PM 2.5 were 190 ng/m 3 , with a range of 60.2 to 862 ng/m 3 over the sampling period. The order of ∑16 PAHs concentration was winter > autumn > summer > spring. The results show that the primary sources of PAH-enriched PM 2.5 are coal combustion, vehicle exhaust, and biomass burning. The annual mean of benzo[a]pyrene (BaP) was 8.37 ng/m 3 , more than 8-fold greater than the BaP annual standard (1 ng/m 3) set by the Chinese State Environmental Protection Agency. The ILCR values for 3 groups (children, teenagers, and adults) over the 4 seasons were between 10 -6 and 10 -4 , indicating a potential health risk from PAHs in Tangshan.	https://pubmed.ncbi.nlm.nih.gov/31622510/	Yes

Reference	Abstract	URL	Peer Reviewed (Yes/No)
Articles ranked, but not summarized			Yes
Aguilar-Dodier LC, Castillo JE, Quintana PJE, Montoya LD, Molina LT, Zavala M, Almanza-Veloz V, Rodríguez-Ventura JG. 2020. Spatial and temporal evaluation of H2S, SO2 and NH3 concentrations near Cerro Prieto geothermal power plant in Mexico. Atmospheric Pollution Research 11 (1): 94-104.	Power generation is associated with toxic emissions. Hydrogen sulfide (H2S) and ammonia (NH3) are toxic gases emitted from geothermal power generation that have negative impacts on health and the environment. Oxidation of H2S leads to formation of SO2 that also has health and environmental effects. The Cerro Prieto geothermal power plant (CP-GPP) is one of the largest in the world and is located 30 km south of Mexicali, a border city between Mexico and the US. Power from this plant is sold to both countries. In order to assess the potential effects of the emissions from the GPP on nearby low-income communities, H2S, SO2 and NH3 concentrations were measured at Nuevo León, El Chimi, and Estación Delta, using passive samplers from November 2013 to June 2014. The highest concentrations of H2S were recorded during periods of high atmospheric stability, and exceeded the limit recommended by the WHO (150 μg m −3, 24-h) three times downwind from the GPP. Similarly, the mean SO2 concentrations at all three sites exceeded the limit established by the NOM-022-SSA1-2010 (288 μg m−3, 24-h), while NH3 concentrations exceeded the limits established by the OEHHA (100 μg m−3, 24-h) eight times at Nuevo León. A backward trajectory analysis indicated transport of air masses from the GPP to El Chimi and Estación Delta sampling sites. The results indicate that GPP's emissions could affect the residents in the surrounding areas, warranting public health action to investigate exposures and risks. @@@@Highlights •H2S and SO2 levels exceeding safety standards were found downwind of the geothermal power plant.•H2S emitted by the local geothermal plant increased the SO2 concentrations.•Mean SO2 concentrations exceeded the Mexican average ambient concentration standard.•NH3 concentrations were measured for the first time at Cerro Prieto geothermal field.•Vulnerable populations downwind of power plant are exposed to high SO2 levels.	https://www.sciencedirect.com/science/article/abs/pii/S1309104219304659	Yes
Bai L, He Z, Ni S, Chen W, Li N, Sun S. 2019. Investigation of PM2.5 absorbed with heavy metal elements, source apportionment and their health impacts in residential houses in the North-east region of China. Sustainable Cities and Society 51: 101690.	Considering the severe polluted situation (e.g., haze) in China, especially during the heating season, it is of great importance to investigate particle matters with absorbed pollutants aiming at source appointment and mitigation strategies. In this work, air purifier filters were utilized to collect particle samples (i.e.,PM.sub.2.5). Metal elements and water-soluble ions in PM.sub.2.5 were analyzed by using the techniques of Inductively coupled optical emission spectroscopy (ICP-OES) and ion chromatography. Next, methods of enrichment factor and main factor analysis were adopted to explore the source of metal elements in indoor PM.sub.2.5 and other indoor particle matters. The potential risk index (RI) of the metal elements was also calculated to assess exposure-health risk. The results showed that particles in the purifier filter were alkaline, SO.sub.4.sup.2- of the water-soluble ions showing the highest concentration. Four main sources of indoor particles were identified: dust, coal dust, dust produced by industrial production and soil dust, with corresponding contribution rates of 56.8%, 21.2%, 12.9% and 6.4% respectively. The potential RI of the metal elements is higher than 600 implying strong ecological hazards. These findings are important for source appointment of indoor particle pollutants further facilitating future mitigation strategies or techniques towards healthy and sustainable living environments.	https://www.sciencedirect.com/science/article/abs/pii/S221067071931203X	Yes
Chen W, Hong J, Yuan X, Liu J. 2020. Environmental impact assessment of monocrystalline silicon solar photovoltaic cell production: a case study in China. Journal of Cleaner Production 112 (Part 1): 1025-1032.	Life cycle assessment on monocrystalline silicon (mono-Si) solar photovoltaic (PV) cell production in China is performed in the present study, aiming to evaluate the environmental burden, identify key factors, and explore approaches for potential environmental improvement. Results show that the impact generated from the categories of human toxicity, marine ecotoxicity, and metal depletion contribute dominantly to the overall environmental burden because of silver (Ag) paste, electricity, and glass consumption. The energy payback time and greenhouse gas emission range from 0.42 to 0.91 years and 5.60–12.07 g CO2 eq/kWh respectively, both of which are lower than the previously reported results in studies in Europe, the United States, and Asia. However, compared with coal-based electricity generation that uses ultra-supercritical technology, the environmental payback time in human toxicity, marine ecotoxicity, and metal depletion categories is quite high because of the direct air emissions of lead, arsenic, mercury, copper, and nickel, as well as the use of Ag. Additionally, utilization of PV systems in regions with high solar radiation values has a high potential environmental benefit from PV systems.	https://www.sciencedirect.com/science/article/abs/pii/S0959652615011130	Yes
Hong Y, Chen J, Zhang F, Zhang H, Xu L, Yin L, Chen Y. 2015. Effects of urbanization on gaseous and particulate polycyclic aromatic hydrocarbons and polychlorinated biphenyls in a coastal city, China: levels, sources, and health risks. Environmental Science & Pollution Research 22 (19): 14919-14931.	Gas/particle distributions of polycyclic aromatic hydrocarbons (PAHs) and polychlorinated biphenyls (PCBs) were measured in Xiamen from May 2009 to March 2010 to evaluate the impacts of urbanization on the fate of persistent organic pollutants (POPs) in the atmospheric environment. In a newly developing area (NDA), the concentrations of 16 PAHs (gas + particle) were significantly higher than that a historically urbanized area (HUA) (p value <0.05), while the trend of 28 PCBs was reversed. Diagnostic ratios and principle component analysis (PCA) implied that atmospheric PAHs in the NDA were mainly derived from petrogenic combustion, including mixed sources of vehicle emissions, biomass burning and oil combustion, while pyrogenic combustion (e.g., traffic and coal combustion) was considered the major source of PAHs in the HUA. Atmospheric PCBs in both HUA and NDA were dominated by TriCBs and PeCBs related to the use of commercial mixtures (Aroclors 1242 and 1254). Based on the toxicological equivalent factor (TEF) approach, total benzo[a]pyrene equivalent values in the HUA and NDA were 1.12 and 2.02 ng m, respectively, exceeding the standard threshold values (1.0 ng m) of China and WHO. Average daily intake of dioxin-like compounds was 0.2 pg kg day in the HUA, which are below the WHO tolerable daily intake level. The results showed that the contribution to the toxic equivalency (TEQ) was dominated by PCB169, PCB105, and PCB81. [ABSTRACT FROM AUTHOR] Copyright of Environmental Science & Pollution Research is the property of Springer Nature and its content may not be copied or emailed to multiple sites or posted to a listserv without the copyright holder's express written permission. However, users may print, download, or email articles for individual use. This abstract may be abridged. No warranty is given about the accuracy of the copy. Users should refer to the original published version of the material for the full abstract. (Copyright applies to all Abstracts.)	https://link.springer.com/article/10.1007/s11356-015-4616-2	Yes
Khairy MA, Lohmann R. 2013. Source apportionment and risk assessment of polycyclic aromatic hydrocarbons in the atmospheric environment of Alexandria, Egypt. Chemosphere 91 (7): 895-903.	In this study, three receptor models [factor analysis/multiple linear regression (FA/MLR), positive matrix factorization (PMF) and UNMIX] were applied seasonally to investigate the source apportionment of PAHs in the atmospheric environment of Alexandria, and a lifetime cancer risk was assessed. ∑44 (gas+particle) PAH concentrations varied from 330 to 1770ngm(-3) and 170-1290ngm(-3) in the summer and winter seasons respectively. PAH concentrations at the industrial sites were significantly higher than at the traffic and residential sites during the winter season (p<0.001). Summer PAH concentrations were significantly higher than the winter season at the traffic sites (p=0.027). Results obtained from the three receptor models were comparable. Vehicle emissions, both diesel and gasoline contributed on average 36.0-49.0% and 19.0-34.0% respectively, natural gas combustion 11.0-27.0% and, during the summer only, also evaporative/uncombusted petroleum sources 8.00-18.0%. Seasonal trends were found for the gasoline emission source. Overall, PMF and UNMIX models afforded better source identification than did FA/MLR. The lifetime cancer risk assessment showed that incremental lifetime cancer risks (ILTCRs) were greater than the acceptable level of 10(-6) through dermal and ingestion routes at all the investigated sites and through the inhalation route at the industrial and traffic sites only. Total ILTCRs (6.64×10(-3)-4.42×10(-2)) indicated high potential risks to the local residents. Published by Elsevier Ltd.	https://www.sciencedirect.com/science/article/abs/pii/S0045653513003081	Yes
Lelieveld J, Evans JS, Fnais M, Giannadaki D, Pozzer A. 2015. The contribution of outdoor air pollution sources to premature mortality on a global scale. Nature 525 (7569): 367-371.	Assessment of the global burden of disease is based on epidemiological cohort studies that connect premature mortality to a wide range of causes, including the long-term health impacts of ozone and fine particulate matter with a diameter smaller than 2.5 micrometres (PM2.5). It has proved difficult to quantify premature mortality related to air pollution, notably in regions where air quality is not monitored, and also because the toxicity of particles from various sources may vary. Here we use a global atmospheric chemistry model to investigate the link between premature mortality and seven emission source categories in urban and rural environments. In accord with the global burden of disease for 2010 (ref. 5), we calculate that outdoor air pollution, mostly by PM2.5, leads to 3.3 (95 per cent confidence interval 1.61-4.81) million premature deaths per year worldwide, predominantly in Asia. We primarily assume that all particles are equally toxic, but also include a sensitivity study that accounts for differential toxicity. We find that emissions from residential energy use such as heating and cooking, prevalent in India and China, have the largest impact on premature mortality globally, being even more dominant if carbonaceous particles are assumed to be most toxic. Whereas in much of the USA and in a few other countries emissions from traffic and power generation are important, in eastern USA, Europe, Russia and East Asia agricultural emissions make the largest relative contribution to PM2.5, with the estimate of overall health impact depending on assumptions regarding particle toxicity. Model projections based on a business-as-usual emission scenario indicate that the contribution of outdoor air pollution to premature mortality could double by 2050.	https://pubmed.ncbi.nlm.nih.gov/26381985/	Yes
Manzetti S. 2013. Polycyclic aromatic hydrocarbons in the environment: Environmental fate and transformation. Polycyclic aromatic compounds (Print) 33 (4): 311-330.	Polycyclic aromatic hydrocarbons are toxic and carcinogenic compounds that occur in the environment and derive from two classes processes: petrogenic and pyrogenic processes. The petrogenic part derives from oil- and drilling activities, including oil disasters, spills, and pollution from industrial sites, refineries, and most importantly traffic exhaust emissions, while the pyrogenic part derives from fires, forest fires, volcanic eruptions, and incineration. PAHs have long degradation periods, and recent studies show high accumulated concentrations in soil, aquatic, and atmospheric environments. Particularly with the advent of the winter season, pollution and pollution migration increases by the atmospheric influences on smog clouds, from air to soil, air to water reserves, and from air to humans. This review maps the recent measurements and concentrations of PAHs worldwide, with particular focus on highly exposed regions such as China, India and former Eastern European countries. Monitoring and mapping the fate of PAH is of particular value to environmental scientists, given the carcinogenic and toxic properties of several PAHs. As also reported in this review, the carcinogenicity and toxicity varies with the chemical and molecular character of PAHs varies with size and shape, and the carcinogenic and toxic effect can be higher according to season, type of fuel and source of pollution, and also by the size of the exposed region/site. PAHs are an ubiquitous pollutant class that has to be included in climate regulations at the same level with CO2 and NOx, given their longer half-life and chemical properties which gives a wide range of toxic derivatives during degradation.	https://www.tandfonline.com/doi/abs/10.1080/10406638.2013.781042?journalCode=gpol20	Yes
Song H, Zhang Y, Luo M, Gu J, Wu M, Xu D, Xu G, Ma L. 2019. Seasonal variation, sources and health risk assessment of polycyclic aromatic hydrocarbons in different particle fractions of PM2.5 in Beijing, China. Atmospheric Pollution Research 10 (1): 105-114.	The ratio of SO2/NO2 together with PM2.5/CO was applied to explain the source of particulate matters (PM) pollution in Beijing. Polycyclic aromatic hydrocarbons (PAHs) bounded with ultrafine particles were investigated as well. A total of 188 graded PM in four-stage size segregated aerosol particles were collected and analyzed by GC-MS in 2016 to investigate the sources and distribution patterns of PAHs in metropolis-Beijing. A significant seasonal variation of 16 PAHs in PM2.5 around in Beijing was observed with 32.93 ± 15.19 ng m −3, 17.77 ± 8.08 ng m−3, 31.61 ± 12.67 ng m−3 and 78.06 ± 40.97 ng m−3 in spring, summer, autumn and winter, respectively. The ratio of SO2/NO2 demonstrated that vehicle emissions significantly contributed to air pollution. On the contrary, the lower ratio of PM2.5/CO showed high direct discharge from combustion. Seasonal distribution patterns of PM0.2/PM2.5 suggested that abundant secondary aerosols were produced in the autumn and winter. The spread of pollutants was not significant in winter. Both the combustion of fuel and coal were the primary sources of PM2.5-bound PAHs. A health risk assessment was represented by benzo[a]pyrene equivalent (BaPeq) indicating potential cancer risk in Beijing. Furthermore, the lifetime excess cancer risk (ECR) was 3.00 × 10 −4, which was higher than the guidelines of USEPA and European Commission, indicating high carcinogenic risk of PM2.5 in Beijing. Therefore, more strictly control measures should be taken to reduce PAHs emissions from coal and vehicle.	https://www.sciencedirect.com/science/article/abs/pii/S1309104218300126	Yes

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Reference	Abstract	URL	Peer Reviewed (Yes/No)
Wu F, Kong S, Yan Q, Wang W, Liu H, Wu J, Zheng H, Zheng S, Cheng Y, Niu Z, Liu D, Qi S. 2020. Sub-type source profiles of fine particles for fugitive dust and accumulative health risks of heavy metals: a case study in a fast-developing city of China. Environmental science and pollution research international 27 (14): 16554-16573.	Sub-type source profiles for atmospheric fine particle (PM 2.5) were still scare in China, which limited the accurate source identification of it. Fugitive dust (including road dust, soil dust, resuspended dust, and construction dust, etc.) was one type of the most important contributors to PM 2.5 and its associated toxic metals held potential threaten to human health. The chemical compositions, sources, and health risks of sub-type fugitive dust deserved an investigation for further accurate control of particles and alleviating human health risks. A total of sixty-five fugitive dust samples were collected in Suzhou, a fast-developing city in southern China, including eleven sub-types of road dust (overpass, main street, collector street, and ordinary street), soil dust (farmland and tree lawn), resuspended dust (site types were corresponding to those of road dust), and construction dust (large construction sites). Chemical analysis of water-soluble ions, elements, and carbonaceous components was carried out to establish the sub-type source profiles of PM 2.5 for fugitive dust. Results showed that crustal elements were the most abundant components of fugitive dust, and soil dust was less polluted by anthropogenic activities. High contents of OC and low contents of EC were found in all the eleven types of dust. Equivalent ratios of anions and cations indicated that the fugitive dust was obviously alkaline. The contents of OC and EC in the four types of road dust were higher than those in other types of dust, while there existed differences among the sub-types of road dust. The NO 3 - /SO 4 2- ratios (0.03-0.09) implied that coal-burning and motor vehicle emission co-existed in Suzhou. Coefficient divergence (CD) values of eleven sub-type source profiles showed that there were certain differences among them, which suggested the possibility of sub-type source identification. Cluster analysis indicated the heavy metals in fugitive dust were mainly from crustal materials, metallurgical manufacturing, vehicle emissions, and industrial activities. The enrichment degree of heavy metals for the four types of road dust was also inconsistent. Heavy metals in road dust and soil dust posed a non-carcinogenic risk to children through direct ingestion, and the non-carcinogenic risk of direct intake of heavy metals was much higher than that of respiratory and skin contact. It was found that the accumulative health risks of heavy metals were higher in densely populated areas, traffic intensive areas, and industrial areas through the spatial analysis. This study firstly discussed the chemical compositions of PM 2.5 for eleven sub-types of fugitive dust in a Chinese city and assessed the accumulative health risks of heavy metals, which could be a demonstration for further related researches.	https://pubmed.ncbi.nlm.nih.gov/32128731/	Yes
Zhang J, Yang L, Mellouki A, Chen J, Chen X, Gao Y, Jiang P, Li Y, Yu H, Wang W. 2018. Diurnal concentrations, sources, and cancer risk assessments of PM 2.5-bound PAHs, NPAHs, and OPAHs in urban, marine and mountain environments. Chemosphere 209: 147-155.	Ambient measurements of PM 2.5 -bounded polycyclic aromatic hydrocarbons (PAHs), nitro-PAHs (NPAHs), and oxy-PAHs (OPAHs) were conducted during the summer in Jinan, China, an urban site, and at Tuoji island and Mt. Tai, two background locations. 3.5 h and 11.5 h sampling intervals in daytime and nighttime were utilized to research the diurnal variations of PAHs, NPAHs, and OPAHs. The concentrations of PAHs, NPAHs, and OPAHs were highest at the urban site and lowest at the mountain site partly due to the influence of the boundary layer. Vehicle emissions at the urban site made a large contribution to high molecular weight PAHs. 1N-PYR and 7N-BaA during morning and night sampling periods in JN were relatively high. Fossil fuel combustion and biomass burning were the main sources for all three sites during the sampling periods. The air masses at the marine and mountain sites were strongly impacted by photo-degradation, and the air masses at the marine site were the most aged. Secondary formation of NPAHs was mainly initiated by OH radicals at all the three sites and was strongest at the marine site. Secondary formation was most efficient during the daytime at the urban and mountain sites and during morning periods at the marine site. The average excess cancer risk from inhalation (ECR) for 70 years' life span at the urban site was much higher than those calculated for the background sites.	https://www.sciencedirect.com/science/article/abs/pii/S0045653518311299	Yes
Grey Literature			
Anderson K, Weis T, Thibault B, Khan F, Nanni B, Farber N. 2013. A costly diagnosis: Subsidizing coal power with Albertans' health. https://www.pembina.org/pub/2424#:~:text=A%20Costly%20DiagnosisSubsidizing%20coal%20power%20with%20Albertans'%20health&text=Alberta%20burns%20more%20coal%20for,its%20electricity%20by%20burning%20coal.&text=These%20decisions%20will%20have%20real,and%20need%20to%20be%20reexamined.	Not available	https://www.pembina.org/pub/2424#:~:text=A%20Costly%20DiagnosisSubsidizing%20coal%20power%20with%20Albertans'%20health&text=Alberta%20burns%20more%20coal%20for,its%20electricity%20by%20burning%20coal.&text=These%20decisions%20will%20have%20real,and%20need%20to%20be%20reexamined	No
Electric Power Research Institute. 2018. Hazardous Air Pollutants (HAPs) Emission Estimates and Inhalation Human Health Risk Assessment for U.S. Coal-Fired Electric Generating Units: 2017 Base Year Post-MATS Evaluation. Technical Report.	Not available	https://www.epri.com/research/products/3002013577	No
Office of Environmental Health Hazard Assessment, California Environmental Protection Agency. Tracking and Evaluation of Benefits and Impacts of Greenhouse Gas Limits in Disadvantaged Communities: Initial Report.	Not available	https://oehha.ca.gov/media/downloads/environmental-justice/report/oehhaab32report020217.pdf	No
Environmental Integrity Project. 2017. Asthma and Air Pollution in Baltimore City.	Not available	https://environmentalintegrity.org/reports/baltimore-asthma/	No
Greenpeace. 2015. Human Cost of Coal Power.	Not available	https://www.greenpeace.org/static/planet4-indonesia-stateless/2019/02/676f10e5-676f10e5-full-report-human-cost-of-coal-power.pdf	No

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