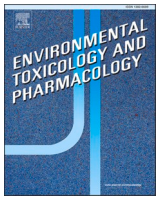
Environmental Toxicology and Pharmacology 125 (2026) 105078

Contents lists available at ScienceDirect

Environmental Toxicology and Pharmacology

journal homepage: www.elsevier.com/locate/etap



Exposure to municipal solid waste incinerators and cancer risk in surrounding populations: A systematic review and meta-analysis

Carolina Capitão [a], Osvaldo Santos [a,b], Raquel Martins [a], Mónica Fialho [a], Rodrigo Feteira-Santos [a], Ricardo R. Santos [a], Murilo Engel [a], Anthony Purece [c], Jurgen Buekers [c], Tommaso Filippini [d], Ana Virgolino [a,*]

[a] Environmental Health Behaviour (EnviHeB) Lab, Instituto de Saúde Ambiental, Faculdade de Medicina da Universidade de Lisboa, Portugal
[b] Unbreakable Idea Research, Portugal
[c] Flemish Institute for Technological Research, Belgium
[d] Environmental, Genetic and Nutritional Epidemiology Research Center (CREAGEN), Department of Biomedical, Metabolic and Neural Sciences, University of Modena and Reggio Emilia, Italy

ARTICLE INFO

Keywords:
Air Pollution
Epidemiological Studies
Incineration
Neoplasms
Risk Assessment

ABSTRACT

Evidence on the carcinogenic effects of municipal solid waste incinerators (MSWI) is inconsistent. This meta-analysis assessed associations between exposure to MSWI emissions and cancer risk. PubMed, Scopus, and Web of Science were searched for ecological, case-control, or cohort studies, evaluating cancer-related outcomes in populations exposed to MSWI. Study quality was evaluated. Random-effects meta-analyses were performed when at least three studies reported the same cancer outcome. Heterogeneity was assessed using I^2 and robustness with leave-one-out sensitivity analyses. Nineteen studies (11 ecological, 4 cohort, 4 case-control; 1996-January 2025) were included. Most ecological studies had poor quality, while cohort and case-control designs were fair-good. Meta-analyses showed modest excess risks for non-Hodgkin lymphoma incidence and lung cancer mortality, with a low certainty of evidence. For other cancers, no consistent and clear associations were found. Overall, current evidence is uncertain to establish causal links between MSWI exposure and cancer. The predominance of ecological designs, limitations in exposure assessment, and methodological heterogeneity contribute to this imprecision.

1. Introduction

At the European level, alongside recycling and reusing, municipal solid waste incineration has been acknowledged as a pivotal element of the circular economy strategy. In municipal solid waste management, municipal solid waste incineration has been particularly applied to residual burning materials that cannot be recovered through circular pathways, with a relevant positive impact also in the reduction of landfill disposal (Directive (EU) 2018/851 of the European Parliament and of the Council of 30 May 2018, amending Directive 2008/98/EC on waste, 2018; European Commission, 2021; European Environment Agency, 2025; Kalmykova et al., 2018; Laureti et al., 2024; UN Environment Programme, 2022). As a result of the growing amount of municipal solid waste resulting from population growth, consumption patterns, and manufacturing practices (namely, in high-income countries), cities have been under increasing pressure to derive and implement more sustainable and efficient waste management practices (Ghisellini et al., 2016; Kafle et al., 2025; UN Environment Programme, 2022).

Current legislation establishes emission limits for municipal solid waste incineration that are considered safe from a public health perspective (Directive (EU) 2010/75/EU of the European Parliament and of the Council of 24 November 2010, on industrial emissions (integrated pollution prevention and control), 2010). Even so, MSWI implies the release and possible accumulation of numerous pollutants into the environment. The emitted compounds may vary according to

* Corresponding author.
E-mail addresses: carolina.capitao@nms.unl.pt (C. Capitão), osantos@medicina.ulisboa.pt (O. Santos), rfmartins@medicina.ulisboa.pt (R. Martins), mfialho@medicina.ulisboa.pt (M. Fialho), rodrigosantos@medicina.ulisboa.pt (R. Feteira-Santos), ricardoreis@medicina.ulisboa.pt (R.R. Santos), murilo.engel@edu.ulisboa.pt (M. Engel), anthony.purece@vito.be (A. Purece), jurgen.buekers@vito.be (J. Buekers), tommaso.filippini@unimore.it (T. Filippini), avirgolino@medicina.ulisboa.pt (A. Virgolino).

https://doi.org/10.1016/j.etap.2026.105078
Received 23 February 2026; Received in revised form 12 June 2026; Accepted 18 June 2026
Available online 21 June 2026

the waste composition and can include a wide range of potentially carcinogenic substances, such as heavy metals, nitrogen oxides, sulfur dioxide, dioxins, and furans (Negri et al., 2020; Valberg et al., 1996). The waste composition also shifted in time, now with more complex, composite materials (Rogers and Jaspers, 2025). For this reason, concerns persist regarding the potential health effects of long-term exposure to these complex mixtures, even at low-dose levels.

Some studies have supported an association between exposure to incineration emissions and increased risk of several cancers and related mortality (Raffetti et al., 2019; Ranzi et al., 2011; Sharma et al., 2013; Vinti et al., 2021). Heavy metals such as cadmium (Cd), arsenic (As), and chromium (CrVI) are well-established human carcinogens (International Agency for Research on Cancer, IARC, 2012), often linked to elevated cancer risk (Barone et al., 2016; Duan et al., 2020). As released compounds from waste incineration tend to concentrate mostly in ash and residues, the populations residing near incinerators or other industrial facilities may be exposed to increased risk (Ancona et al., 2015; Bottini et al., 2025; Sharma et al., 2013; Valizadeh et al., 2024). While most studies have focused on single agents, complex mixtures of chemical compounds may act synergistically, thus amplifying potential carcinogenic and mutagenic effects (Carpenter et al., 2002; González et al., 2019; Yao et al., 2021).

In parallel with increasingly stricter emission controls, advances in knowledge over the last few decades have been made possible due to improved evaluation and monitoring methods for studies targeting populations living near municipal solid waste incineration sites (Ancona et al., 2015; Cordioli et al., 2013; Negri et al., 2020). Nevertheless, findings remain contradictory, with studies covering first-generation incinerators often reporting increased risks for overall cancer, soft-tissue sarcoma, non-Hodgkin lymphoma (NHL), or pancreatic cancer. In contrast, studies focused on second- or third-generation incinerators produced inconsistent or null associations (Negri et al., 2020). Despite this, methodological challenges have contributed to the state of the art with conflicting evidence in the field (Negri et al., 2020; Vinti et al., 2021). Small sample sizes, short follow-up periods, and predominantly ecological designs tend to limit statistical power and causal inference (Negri et al., 2020; Ranzi et al., 2011). Moreover, a non-systematic control of confounding factors—e.g., smoking, socioeconomic status (SES), occupational exposure—hinders proper result interpretation (Ancona et al., 2015; Negri et al., 2020; Ranzi et al., 2011; Vinti et al., 2021). Other elements that may have also contributed to the ongoing uncertainty include: exposure misclassifications, inappropriate latency periods between exposure and disease incidence, or incomplete residential narratives (Negri et al., 2020; Ranzi et al., 2011).

Moreover, because the type of waste directly influences the mixture and concentration of pollutants released, combining different incinerator types may introduce additional variability and bias (Baek et al., 2022). To address this limitation, we conducted a systematic review and meta-analysis restricted to studies assessing exposure to municipal solid waste incinerators (MSWI). This focused approach allowed for a reduction in heterogeneity stemming from different waste streams and enabled a more precise evaluation of long-term cancer risks in surrounding populations.

This systematic review and meta-analysis aimed to assess whether exposure to MSWI is associated with cancer risk in human populations. Specifically, it aimed to synthesize the available epidemiological evidence across study designs and cancer types.

2. Methods

This systematic review with meta-analysis was performed following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines (Page et al., 2021). The protocol was registered in the International Prospective Register of Systematic Reviews (PROSPERO) on April 1, 2024 (CRD42024526207).

2.1. Eligibility criteria

The inclusion criteria comprised original peer-reviewed epidemiological studies written in English, including observational (i.e., cohort, case-control, or cross-sectional), ecological, spatial, or quasi-experimental designs. The studies should have assessed the association between exposure to municipal solid waste incinerator (MSWI) emissions from all types of waste incinerators of domestic/municipal/urban solid waste material (regardless of the incinerator' construction period and of legal emission limits), and cancer incidence, prevalence, related mortality, or hospitalizations, providing risk estimates comparing exposure with no or low-dose exposure. Exposure should have been defined by residential proximity, residential geocoding, pollutants dispersion modelling, or other methods.

The following studies were excluded: i) experimental in vitro and animal studies, case series, case reports, review articles (including narrative, scoping, or systematic reviews), commentaries and opinion pieces, or conference abstracts; ii) studies on occupational exposure to incinerators; and iii) studies on general industrial pollution wherein incinerator emissions were not evaluated in a disaggregated way.

For narrative synthesis, studies were grouped by outcome measures according to the type of health outcome (incidence, prevalence, mortality, or hospitalization) and cancer type.

2.2. Information sources

The search for eligible studies was conducted in the bibliographic databases PubMed (via NCBI), Scopus (Elsevier), and Web of Science Core Collection (Clarivate). Reference lists of all included studies, as well as those of systematic review papers, were manually screened for identification of additional records. All sources were last searched on January 6, 2025 (the final update of the systematic search conducted prior to manuscript submission). Eligible records available in the searched sources from database inception up to this final search date were considered for inclusion.

2.3. Search strategy

The search strategy was developed using a combination of relevant key terms in English (MeSH terms, text words in titles, abstracts, keywords, and their equivalents), describing the exposure and health outcomes. These terms were adapted for each database, with the full list of used terms and specific search strings detailed in supplementary material (Table S1). No publication date limits were applied, allowing for the inclusion of eligible records available from database inception up to the final search date. The only additional filter was applied in the Web of Science database, where the search was restricted to document types categorized as articles. The results were exported from the databases to a Microsoft Office Excel® document.

2.4. Selection process

After duplicate records were removed, authors in pairs independently screened titles and abstracts against the inclusion and exclusion criteria using Microsoft Office Excel®. Then, full-text records were retrieved and independently reviewed in duplicate. Decisions were compared, and disagreements were resolved through discussion and consensus. If consensus could not be reached, a third author was consulted to make the final decision. No automation or translation tools were used during the screening process.

2.5. Data collection process

Data from each record were extracted by one author and validated by a second author. As with the study selection process, disagreements were resolved through discussion and consensus, with a third author

consulted if consensus could not be reached. Data were recorded in an Excel® spreadsheet, and no automation or translation tools were used during the data collection process.

2.6. Data items

The following data were recorded: first author's name, publication year (for papers published online ahead of print, the final publication date was used only to record the publication year and was not applied as an eligibility cut-off), study design, country, study period, incinerator type, exposure assessment method, duration of exposure, outcomes, cancer type(s), sex of participants, population type, population/sample size, exposure category, adjustment variables, effect size type, effect size with 95% confidence intervals, and key findings. The classification of cancer diagnoses followed the system reported in each study by the authors (e.g., ICD or ICD-O).

For each study, relevant results were extracted when reported for different combinations of health outcomes (e.g., incidence, mortality), cancer types, and populations (e.g., female, total population). However, when multiple results were reported for the same combination of health outcome, cancer type, and population, the following criteria were applied to extract a single result per combination: i) if exposure was classified into multiple levels, the effect size comparing the lowest with the highest exposure group was extracted; ii) if exposure was categorized based on distance from the incinerator, the effect size comparing the nearest to the farthest areas was extracted; and iii) when both adjusted and unadjusted estimates were reported, the adjusted values were extracted.

Furthermore, potential overlap between studies was assessed, particularly for those conducted in the same country or referring to the same MSWI. When the facility was the same, this was documented and considered in the interpretation of results. For the meta-analysis, this was also taken into account.

In cases where information was unclear or missing, authors were contacted for clarification or additional data. The information retrieved from one of the included papers was corrected by the corresponding author via e-mail. If effect size and confidence intervals were not explicitly reported, they were calculated from available data or data provided by the authors.

2.7. Study quality assessment

The quality of the included studies was assessed using the National Institutes of Health's Study Quality Assessment (NIH-QA) Tools for Observational Cohort and Cross-Sectional Studies and Case-Control Studies, as applicable (National Institutes of Health, 2014). Each record was evaluated at the study level for potential risks of selection bias, information bias, measurement bias, and confounding. Based on the NIH-QA criteria, studies were classified as having "good," "fair," or "poor" quality.

To ensure reliability, quality assessments were independently conducted by two reviewers. Any disagreements were resolved through discussion and consensus to achieve final classifications.

2.8. Effect measures

Due to variability in study designs and reporting methods among the included records, different effect measures were used to report the association between exposure to MSWI emissions and cancer incidence or mortality. These measures included relative risks (RR), odds ratios (OR), hazard ratios (HR), standardized incidence ratios (SIR), and standardized mortality ratios (SMR).

2.9. Synthesis methods

Studies eligible for qualitative synthesis were tabulated by cancer type, outcome measure, and study characteristics (e.g., design, exposure assessment method, and follow-up period). When three or more studies reported the same outcome (i.e., specific cancer type and outcome measure), a random-effects meta-analysis was conducted to account for potential variability in study populations, methods of exposure assessment, and outcome definitions across studies, using the DerSimonian–Laird estimator as implemented in the metagen function from the library "meta" (Balduzzi et al., 2019). Analyses were stratified by effect measure (RR, OR, HR, SMR/ SIR), and an overall combined effect size was calculated by aggregating the different measures (RR, OR, and HR; SMR and SIR). This decision was made to account for heterogeneity in reporting across studies while allowing for a comprehensive synthesis of the association. By using this approach, we aimed to maximize data utilization and provide a robust estimate of the effect.

In cases where effect sizes and confidence intervals were not explicitly reported, they were calculated from the available data or from additional information provided by study authors (Higgins et al., 2024). Missing or unclear information was clarified with the authors whenever possible.

Results of the meta-analyses were visually presented using forest plots, displaying individual study estimates, weights, confidence intervals, and overall pooled estimates. Heterogeneity measures, including Tau^2 and I^2 statistics, and stratified results were clearly reported in these plots.

Further stratified analyses for eligible studies were planned, based on overall study quality, methods of exposure assessment (e.g., residential proximity or dispersion modelling), and exposure duration, but were not possible due to the insufficient number of studies available.

Before quantitative synthesis, potential overlap between studies was assessed by comparing geographical areas, data sources or cancer registries, study periods, cancer outcomes, and reported numbers of cases or participants. To avoid duplicate inclusion of the same study population, each meta-analysis included only one effect estimate per independent study population, cancer outcome, outcome measure, and exposure contrast. Studies were considered independent when they used different observed-case datasets, diagnostic periods, cancer outcomes, or geographical populations. The effect estimates from different populations in the same study, i.e., participants of different sex or age group, were also treated as independent.

Sensitivity analyses were performed by examining the influence of individual studies (or effect estimate in the case of studies that present data for more than one group of participants) through leave-one-out analyses, wherein the meta-analysis was repeated after removing one study at a time. This approach was applied to identify any disproportionate influence of individual studies on the pooled effect size. The results of leave-one-out analyses were interpreted with caution in cases where meta-analyses included a small number of studies, as the exclusion of a single study could substantially alter the pooled estimate. As no direct overlap in participants, deaths, or observed cancer cases was identified among studies contributing to the same outcome-specific meta-analysis, a sensitivity analysis excluding overlapping datasets was not needed.

Analyses were performed using R (version 4.4.1) (R Core Team, 2024) and the meta package (Balduzzi et al., 2019).

2.10. Reporting bias assessment

Potential reporting biases were evaluated in all meta-analyses. Funnel plots were visually inspected for asymmetry, and Egger's test (Egger et al., 1997) was used to statistically assess funnel plot asymmetry when at least 10 effect estimates were included.

2.11. Certainty assessment

The strength of evidence for each outcome was assessed with the Grading of Recommendations, Assessment, Development and

Evaluation (GRADE) system (Atkins et al., 2004). This approach entails five domains that may lead to a downgrade in the certainty of the evidence when limitations are identified in each domain: risk of bias, inconsistency, indirectness, imprecision, and publication bias. The overall certainty for each outcome was rated as "high", "moderate", "low", or "very low".

3. Results

3.1. Study selection

The search retrieved 8428 records. After duplicate removal, 6255 titles and abstracts were screened, which resulted in the inclusion of 18 studies. After screening the reference lists of included papers (n = 827), one more was included. In total, 19 studies met the inclusion criteria. Detailed information on the selection of the studies included is presented in Fig. 1.

3.2. Study characteristics

Descriptive characteristics of the included studies are presented in Table 1. Publication years ranged from 1996 to January 2025, reflecting almost three decades of research in the area. The study periods covered cancer cases from as early as the mid-1970s to as late as 2018, while exposure assessments typically spanned earlier decades, in some cases beginning in the early 1970s.

Most studies were performed in Europe (n = 13), mainly in France (n = 7) and Italy (n = 3), followed by the United States (n = 5). The included studies followed different designs: eleven were ecological, four case-control, and four cohort studies (some studies relate to the same incinerator site, as indicated by asterisks in Table 2). Exposure to MSWI emissions was defined heterogeneously, including residential proximity (n = 9; 1–15 km), combined proximity and duration (n = 1), dispersion modelling (n = 7), and average emission levels (n = 2).

3.3. Study quality

The methodological quality varied by design (Tables 2 and 3). Among the 11 ecological studies, the majority were rated as "poor", with only a few assessed as "fair". These studies generally had clear research questions and outcome measures, but systematic limitations arose from their cross-sectional nature, namely, exposure not being assessed before outcome measurement. In addition, follow-up windows may have been too short to capture long-latency cancer outcomes. Additional weaknesses were frequently found in the exposure definition and assessment. Cohort studies demonstrated higher methodological rigor, with three out of four rated as "good". Strengths included well-defined study populations, robust outcome assessment, and appropriate statistical analyses, while some limitations were observed in exposure assessment and the lack of information on blinding of outcome assessors. Case-control studies were evenly split between "fair" and "good" quality. They typically had clear case definitions, adequate population representation, and appropriate analyses, but recurrent shortcomings were observed in concurrent controls, temporality of exposure assessment, exposure measurement, and blinding.

3.4. Summary of results

Across the 19 included studies, 138 effect estimates were extracted, corresponding to 34 distinct cancer types (Supplementary material Table S2). Fifteen studies reported cancer incidence outcomes, five mortality outcomes, and one study reported hospitalization outcomes. Ten studies described multiple cancer types, while others focused on a single type, mainly NHL or breast cancer. The most frequently investigated cancer types were NHL (n = 11) and lung cancer (n = 8). Ecological studies often addressed different digestive, respiratory, or hematologic cancers within a single analysis. Cohort studies contributed primarily to NHL, while also reporting on other outcomes. Case-control designs focused on breast cancer and, NHL.

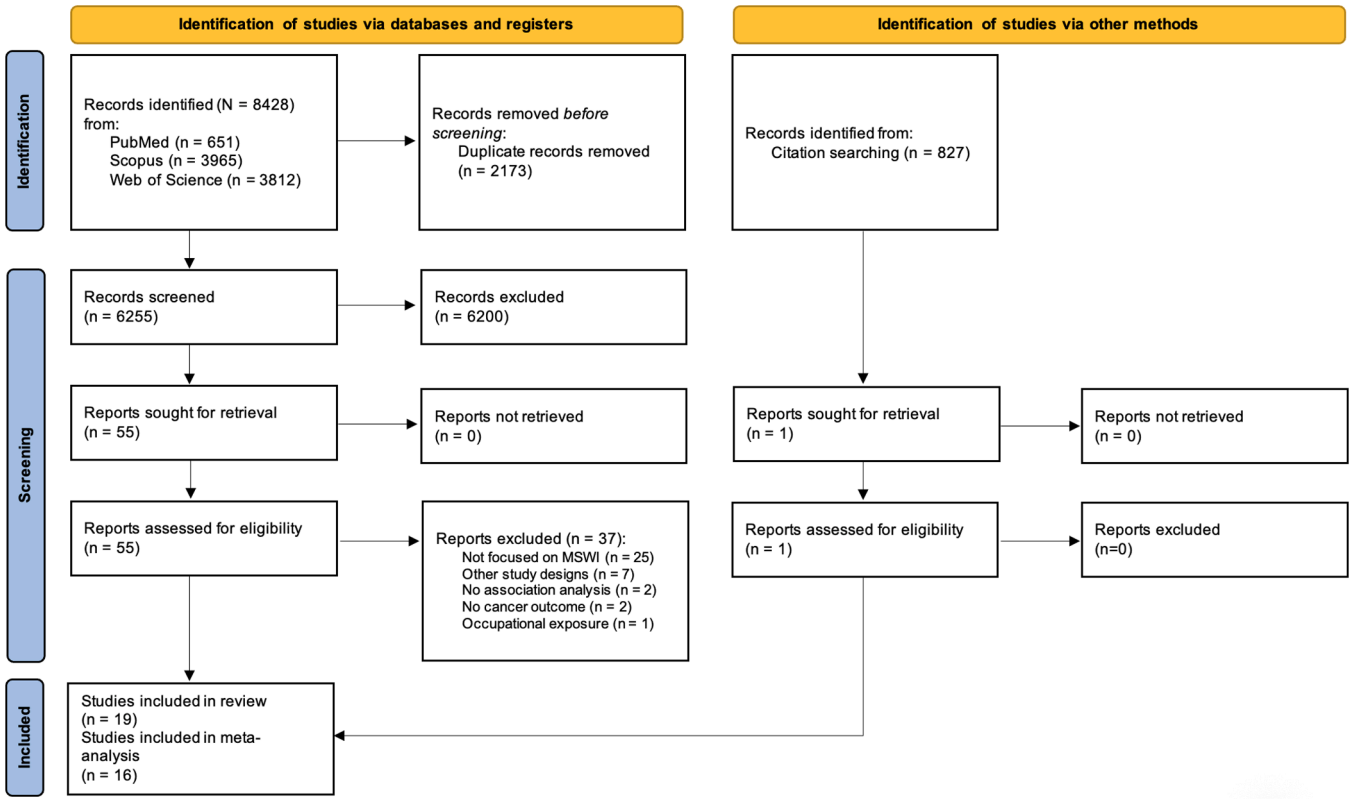


Fig. 1. Study selection flowchart.

Table 1
Descriptive characteristics of the included studies.

Reference	Study design	Country	Study period	Incinerator type	Exposure assessment method	Population	Population/ cases	Cancer types (classification system)
Incidence only								
Elliot, 1996	Ecological	Great Britain	Outcome: 1974–86 (England), 1974–84 (Wales), 1975–87 (Scotland)	Municipal solid waste incinerators (n = 52); household, commercial and/ or industrial waste	Residential proximity Exposure: living within 3 km from an incinerator Counterfactual: national rates (regional adjusted) Lag period (of incinerator activity): 10 years for all cancers, stomach, colorectal, liver, lung, connective and bladder; 5 years for lymphatic and hematopoietic tissues and non-Hodgkin	All ages, both sexes combined	Total population: 3 400 000 Total cases (all cancers): 114 394	Incidence: all cancers, bladder, connective, colorectal, liver, lung, lymphatic and hematopoietic tissues, non-Hodgkin lymphoma, stomach (ICD−8 for England and Wales and ICD−9 for Scotland)
Federico, 2010	Ecological	Italy	1991–2005	Solid urban waste and non-dangerous special waste incinerator (140,000 tons of waste per year, equipped with a dry scrubbing of flue gas that is based on sodium bicarbonate for acid pollutants; activated carbon for dioxins/furans and heavy metal absorption and a selective non-catalytic reducer for nitrogen oxide abatement)	Residential proximity Exposure: longest period of residence in a census unit within 2 km from incinerator Counterfactual: municipality rates (where the MSWI is located)	Stratified by sex and both sexes combined	Total population: 175 502 Total cases (all cancers): 16 443	Incidence: all cancers, bronchus and trachea, colorectal, laryngeal, leukaemia, liver and bile duct, lung, non-Hodgkin lymphoma, soft tissue sarcoma (ICD-O−3)
VoPham et al. (2022)	Ecological	United States	Exposure: 1987–2007 Outcome: 2000–2016	Municipal solid waste incinerators (n = 57)	County-level average annual emissions from MSWI Exposure: county of residence with estimated average annual emissions from MSWI > 2.31 g TEQ/ year Counterfactual: county of residence with estimated average annual emissions from MSWI of 0 g TEQ/year	≥ 18 years of age, both sexes combined	Total cases: 90 359 Exposed cases: 14 133	Incidence: hepatocellular carcinoma (ICD-O−3)
Mariné Barjoan, 2020	Ecological	France	2005–2014 (reported outcomes: 2010–2014)	Domestic waste incineration facility	Dispersion modelling (dioxin emissions): air flow, height of the stack, specific topography and the occurrence of complex meteorological of the site, estimated concentrations generated, and theoretical volume of smoke emitted Exposure: residence at the time of diagnosis in area exposed to atmospheric fallout from the smoke plum (mean dioxin concentrations P90: ≥17.9 ng/m^2/year; P50: 4.25–17.8 ng/m^2/year) Counterfactual: residence in the	Stratified by sex	Exposed population: 87 462 (53.9% women) Non-exposed population: 996 512 (52.7% women) Exposed cases (all cancers): 6 165 (48.1% women) Non-exposed cases (all cancers): 74 700 (46.7% women)	Incidence: all cancers, all cancers except skin, acute myeloid leukaemia, bladder, breast, Hodgkin lymphoma, laryngeal, liver, lung, multiple myeloma, myelodysplastic syndromes, myeloproliferative syndromes, non-Hodgkin lymphoma, pleural mesothelioma, soft tissue sarcoma (ICD−10 and ICD-O−3)

(*continued on next page*)

Table 1 (*continued*)

Reference	Study design	Country	Study period	Incinerator type	Exposure assessment method	Population	Population/ cases	Cancer types (classification system)
					remainder of the department (mean dioxin concentration <4.25 ng/m^2/year)			
Goria, 2009*	Ecological	France	Exposure: 1972–1990 Outcome: 1990–1999	Municipal solid waste incinerators (n = 16)	Dispersion modelling (second generation Gaussian model to estimate atmospheric dispersion and ground-level deposit): estimations obtained from experts, pollutant characteristics, stack height, meteorological data (wind speed and direction, temperature, atmospheric stability) and environmental characteristics such as surface topography and soil roughness Exposure: index of exposure of the geographical unit of residence at the time of diagnosis (based on mean cumulative ground-level dioxin deposits) Lag period: 10 years for solid tumours and 5 years for leukaemia.	≥ 14 years of age, stratified by sex and both sexes combined	Total person-years: 25 000 000 Total cases: 135 000	Incidence: all cancers, breast, liver (NR)
Viel, 2008b*	Ecological	France	Exposure: 1972–1985 Outcome: 1990–1999	Municipal solid waste incinerators (n = 13)	Dispersion model (second-generation Gaussian atmospheric diffusion model): quantitative estimates obtained above from the experts, chimney height and diameter, plume emission temperature, particle size and density, topographic indicators (roughness, relief), local weather data Exposure: residence in census blocks with average cumulative ground-level concentration over the 90th percentile (1.78 × 10–2 μg/m^2/year) Counterfactual: residence in census blocks with average cumulative ground-level concentration under 2.5th percentile (1.25 × 10–4 μg/m^2/ year)	≥ 15 years of age, stratified by sex and both sexes combined	Total cases: 3 974 (46.0% women)	Incidence: non-Hodgkin lymphoma (ICD-O−2)
Viel, 2000**	Ecological	France	1980–1995	Municipal solid waste incinerator (processed 67 thousand metric tons of waste in 1998)	Residential proximity (spatial-time cluster) Exposure: residence in statistical units around the incinerator Counterfactual: incidence rates from the whole department stratified by gender and 5-year age groups.	Both sexes combined	110 total cases of soft tissue sarcoma; 803 total cases of non-Hodgkin lymphoma; and total 176 cases of Hodgkin disease	Incidence: Hodgkin lymphoma, non-Hodgkin lymphoma, soft tissue sarcoma (ICD-O)
Floret, 2003**	Case-control	France	1980–1995	Municipal solid waste incinerator (processed 67 thousand metric tons of waste in 1998)	Dispersion model of dioxins (second-generation Gaussian dispersion model): meteorological data, surface topography and	All ages, both sexes combined	Total cases: 222 Exposed cases: 31 Non-exposed cases: 42 Total controls: 2	Incidence: non-Hodgkin lymphoma (ICD-O)

(*continued on next page*)

Table 1 (*continued*)

Reference	Study design	Country	Study period	Incinerator type	Exposure assessment method	Population	Population/ cases	Cancer types (classification system)
					obstacle descriptions, stack characteristics and dioxin emission rate from the solid waste incinerator) Exposure: residence in high estimated dioxin relative exposure areas (modelled ground-level concentration of 0.0004–0.0016 pg/m^3) No-exposure: residence in very low dioxin relative exposure areas (<0.0001 pg/m^3)		220 Exposed controls: 146 Non-exposed controls: 441	
Viel, 2008a**	Population-based case-control	France	1996–2002	Municipal solid waste incinerator (processed 67 thousand metric tons of waste in 1998)	Dispersion model (first-generation Gaussian-type): meteorological data (5 years of data for wind speed, wind direction, pressure, temperature, and Pasquill atmospheric stability classes), simplified surface topography, plume rise, stack characteristics, and future dioxin emission rate from the MSWI Exposure: residence in high estimated dioxin relative exposure areas (modelled ground-level concentration of 0.0004–0.0016 pg/m^3) No-exposure: residence in very low dioxin relative exposure areas (<0.0001 pg/m^3)	Women ≥ 20 years of age.	Total cases: 434 Exposed cases: 15 Non-exposed cases: 91 Total controls: 2170 Exposed controls: 127 Non-exposed controls: 453	Incidence: invasive breast (ICD-O−3)
Pronk, 2013	Population-based case-control	United States	1998–2000	Municipal solid waste incinerators	Residential proximity Exposure: ever lived within 3 km (average emission level in 1995: 15.77 ng TEQ/yr) No-exposure: never lived within 3 km Lag period: 15 years	20–74 years of age, both sexes combined	Total cases: 969 Exposed cases: 3 Total controls: 749 Exposed controls: 7	Incidence: non-Hodgkin lymphoma (NR)
Praud et al. (2025)	Case-control nested cohort	France	1990–2011	Household waste incinerator	Estimated annual exposure index based on residential address and dispersion modelling Exposure: increments of 7.4 μg TEQ/m^2 from MSWI	Women	Total cases: 5222 Total controls: 5222	Incidence: breast (NR: confirmed by pathology report)
VoPham et al. (2020)	Prospective cohort	United States	1989–2013	Municipal solid waste incinerator	Residential proximity and duration of exposure Exposure: residence up to 3 km from a MSWI for at least 6 years No-exposure: did not reside with 3 km from a MSWI Lag period: 6 years	Women	Total participants: 112 397 Total person-years: 2 302 566 Exposed person-years: 12 634 Non-exposed person-years: 2 266 905 Total cases: 3 840 Exposed cases: 37 Non-exposed: 3 767	Incidence: invasive breast (NR: medical record review)
Fisher, 2024	Cohort	United States	Exposure: 1980–1995 Outcome: 1995–2011	Municipal solid waste incinerators	Inverse distance-weighted emissions model with wind adjustment, using	50–71 years of age, both sexes combined	Total participants: 451 410 Total cases: 6	Incidence: non-Hodgkin lymphoma (NR)

(*continued on next page*)

Table 1 (*continued*)

Reference	Study design	Country	Study period	Incinerator type	Exposure assessment method	Population	Population/ cases	Cancer types (classification system)
					residential proximity, dioxin emissions, and meteorological data Exposure: residence within 3 km of an MSWI and falling into the highest tertile of wind-adjusted average dioxin emissions No-exposure: residence beyond 3 km of any MSWI, or residence within 3 km of an MSWI but with zero estimated wind-adjusted average dioxin emissions Lag period: 15 years		467 Exposed cases: 20 Non-exposed cases: 6 424	
Rhee, 2023	Prospective cohort	United States	2003–2018	Municipal solid waste incinerators	10-year distance- and toxic equivalency quotient (TEQ)-weighted average dioxin emissions indices, calculated using emissions trends (1987–2000) Exposure: residence within 3 km of a MSWI and an average dioxin emissions index (AEI) equal to or above the median value (≥0.34 g TEQ/km^2) during the 10 years before study enrolment No-exposure: residence not within 3 km of any MSWI facility emitting dioxins (i.e., AEI = 0 g TEQ/km^2 for MSWIs within 3 km) during the same 10-year period Lag period: 10 years	Women, 35–75 years of age	Total participants: 35 908 Total cases: 2670 Exposed cases: 22 Non-exposed cases: 2 639	Incidence: breast (NR)
Incidence and mortality								
Reeve, 2013	Ecological	England	1998–2008	Municipal waste incinerators (capacity in excess of 150 000 tons per annum of waste material)	Residential proximity Exposure: residence in geographical units within 10 km from incinerator Counterfactual: matching geographic areas based on demographic structure, household composition; housing; socioeconomic character; employment; and industry sector	All ages and < 15 years of age, both sexes combined	Exposed population: 2 657 000 Non-exposed population: 2 572 000 NR	Adult incidence: leukaemia, lung, non-Hodgkin lymphoma Childhood incidence: all cancers, leukaemia Adult mortality: liver (ICD−10)
Romanelli, 2019	Population-based retrospective cohort	Italy	2001–2014	Municipal waste incinerator (65,000 tons of waste per year)	Dispersion model (CALMET-CALPUFF method): environmental and meteorological data for 2015 and 2006, and considering the orography of the area Exposure: residence in high exposure area (NOχ-MWI >0.031) Counterfactual: residence in low exposure area (NOχ-MWI ≤0.013)	Stratified by sex	Total participants: 132 293 Total person-years: 1 092 817 (52.6% women) Exposed person-years: 335 760 Non-exposed person-years: 195 743	Mortality and hospitalizations: colorectal, connective and soft tissues, leukaemia, liver, lung, lymphatic and hematopoietic tissues, non-Hodgkin lymphoma, stomach (ICD−9)
Mortality only								

(*continued on next page*)

Table 1 (*continued*)

Reference	Study design	Country	Study period	Incinerator type	Exposure assessment method	Population	Population/ cases	Cancer types (classification system)
García-Perez, 2013	Ecological	Spain	1997–2006	Solid urban (municipal) and special waste	Residential proximity Exposure: residence in a town within 5 km from an incinerator Counterfactual: national rates adjusted for age group, sex and five-year period. Lag period (of incinerator activity): 10 years for solid tumours and 1 year for leukaemia	Stratified by sex and both sexes combined	Exposed cases (all cancers): 13 051	Mortality: all cancers, bladder, brain, colorectal, connective and soft tissues, gallbladder, Hodgkin lymphoma, kidney/ renal, leukaemia, liver, lung, ovarian, pleural, skin, stomach, thyroid, vulvar and vaginal (ICD−9 and 10)
Salerno, 2015	Ecological	Italy	1988–2009	Urban solid waste incinerator	Residential proximity Exposure: residence within 15 km from the incinerator Counterfactual: residence in a reference area (not exposed to the incinerator) Lag period: 10 years	General population and stratified by sex	Exposed population: 8 682 (51.8% women) Non-exposed population: 7 018 (50.5% women)	Mortality: bladder, breast, colorectal, kidney/renal, laryngeal, leukaemia, liver and bile duct, lung, lymph nodes, multiple myeloma, nervous system, ovarian, pleural, stomach, uterus (NR)
Gouveia, 2010	Ecological	Brazil	1998–2002	Solid waste incinerator	Residential proximity Exposure: residence within 1 km from the incinerator Counterfactual: municipality rates adjusted to sex and age group	≥ 40 years, both sexes combined and children < 5 years of age	*Adult* Total population: 634 993 Exposed population: 16 975 *Children* Total population: 92 894 Exposed population: 2 311	Adult mortality: laryngeal, liver, lung, non-Hodgkin lymphoma Childhood mortality: all cancers, leukaemia (ICD−10)

ICD, International Classification of Diseases; MSWI, Municipal Solid Waste Incineration; MWI, municipal waste incinerator; $NO\chi$, nitrogen oxides; NR, Not reported; TEQ: Toxic Equivalents

* same MSWI (Besançon).

** same MSWI (Isère, Bas Rhin, Haut Rhin, and Tarn)

Table 2

Summary of study quality assessment of ecological and cohort studies using the National Institutes of Health Tool for Observational Cohort and Cross-Sectional Studies.

Study	Design	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10	D11	D12	D13	D14	Overall
Elliot, P (1996)	Ecological	✓	✗	✓	✓	✓	✗	✗	✓	✗	✗	✓	✓	●	✓	Poor
Federico, M (2010)	Ecological	✓	✓	✓	✓	✓	−	−	✓	✗	✓	✓	✓	●	✓	Fair
García-Perez, J (2013)	Ecological	✓	✓	✓	✓	✓	✓	−	✗	✗	✗	✓	✓	●	✓	Fair
Goria, S (2009)	Ecological	✓	✓	−	✓	✓	−	−	✓	✗	−	−	−	●	✓	Poor
Gouveia, N (2010)	Ecological	✓	✓	✓	✓	✗	✗	✗	✓	✗	✗	✓	✓	●	✗	Poor
Mariné Barjoan, E (2020)	Ecological	✓	✓	✓	✓	✓	✗	✗	✗	✗	✗	✓	✓	●	✗	Poor
Reeve, NF (2013)	Ecological	✓	✓	✓	✓	✓	✗	✗	✗	✗	✗	✓	✓	●	✓	Poor
Viel, JF (2000)	Ecological	✓	✓	✓	✓	✗	−	−	✗	✗	−	✓	✓	●	✗	Poor
Viel, JF (2008a)	Ecological	✓	✓	✓	✓	✗	✗	✗	✗	✗	✗	✓	✓	●	✓	Poor
VoPham, T (2022)	Ecological	✓	✓	✓	✓	✓	✗	✗	✓	✗	✗	✓	✓	●	✓	Fair
Salerno, C (2015)	Ecological	✓	✗	✓	✓	✗	✗	✗	✗	✗	✗	✓	✓	●	✗	Poor
		100%	82%	91%	100%	64%	9%	0%	45%	0%	9%	91%	91%	-	64%	
Romanelli, AM (2019)	Retrospective cohort	✓	✓	✓	✓	✓	✓	−	✗	✓	✓	✓	✓	✓	✓	Good
VoPham, T (2020)	Prospective cohort	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	Good
Fisher, JA (2024)	Prospective cohort	✓	✓	✗	✓	✓	✓	−	✓	✗	✗	✓	✓	✓	✓	Fair
Rhee, J (2023)	Prospective cohort	✓	✓	✓	✓	✓	✓	✓	✓	✓	✗	✓	✗	✓	✓	Good
		100%	100%	75%	100%	100%	100%	50%	75%	75%	50%	100%	75%	100%	100%	

Legend: ✓ Yes ✗ No − Cannot decide ● Not applicable

D1. Research question; D2. Study population; D3. Participation rate; D4. Groups recruited from the same population; D5. Sample size justification; D6. Exposure assessed prior to outcome measurement; D7 Sufficient timeframe to see an effect; D8. Different levels of the exposure of interest; D9. Exposure measures and assessment; D10. Repeated exposure assessment; D11. Outcome measures; D12. Blinding of outcome assessors; D13. Follow-up rate; D14. Statistical analyses

D1. Research question; D2. Study population; D3. Participation rate; D4. Groups recruited from the same population; D5. Sample size justification; D6. Exposure assessed prior to outcome measurement; D7 Sufficient timeframe to see an effect; D8. Different levels of the exposure of interest; D9. Exposure measures and assessment; D10. Repeated exposure assessment; D11. Outcome measures; D12. Blinding of outcome assessors; D13. Follow-up rate; D14. Statistical analyses

Meta-analyses were possible for outcomes reported by at least three studies, including NHL incidence (n = 9), incidence (n = 3) and mortality (n = 4) of lung cancer, breast cancer incidence (n = 4), incidence (n = 3) and mortality (n = 4) of liver cancer, soft tissue sarcoma

Table 3
Summary of study quality assessment of case-control studies using the National Institutes of Health Tool for Case-Control Studies.

Study	Design	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10	D11	D12	D13	Overall
Floret, N (2003)	Case-control	✓	✓	✓	✗	✓	✓	✓	✓	✗	✗	✗	−	✓	Fair
Pronk, A (2013)	Case-control	✓	✓	✓	✗	✓	✓	✓	✓	✓	✓	✗	−	✓	Good
Viel, JF (2008b)	Case-control	✓	✓	✓	✓	✓	✓	✓	✓	✗	✗	✗	−	✗	Fair
Praud, D (2025)	Case-control nested cohort	✓	✓	−	✗	✓	✓	✓	✓	✓	✓	✓	✓	✓	Good
		100%	100%	75%	25%	100%	100%	100%	100%	50%	50%	25%	25%	75%	

Legend: ✓ Yes ✗ No − Cannot decide ● Not applicable
D1. Research question; D2. Study population; D3. Target population and case representation; D4. Sample size justification; D5. Groups recruited from the same population; D6. Inclusion and exclusion criteria applied uniformly; D7. Case and control definitions; D8. Random selection of study participants; D9. Concurrent controls; D10. Exposure assessed prior to outcome measurement; D11. Exposure measures and assessment; D12. Blinding of exposure assessors; D13. Statistical analysis

D1. Research question; D2. Study population; D3. Target population and case representation; D4. Sample size justification; D5. Groups recruited from the same population; D6. Inclusion and exclusion criteria applied uniformly; D7. Case and control definitions; D8. Random selection of study participants; D9. Concurrent controls; D10. Exposure assessed prior to outcome measurement; D11. Exposure measures and assessment; D12. Blinding of exposure assessors; D13. Statistical analysis

incidence (n = 3), colorectal cancer mortality (n = 3), stomach cancer mortality (n = 3), and leukaemia mortality (n = 3). In total, estimates from 16 out of the 19 studies were included in the meta-analysis. Summary estimates are presented in Table 4; forest plots are presented in the supplementary material.

3.4.1. *Digestive system*

Two studies investigated the incidence of colorectal cancer (Elliott et al., 1996; Federico et al., 2010). Elliot (1996) observed a modestly elevated incidence within 3 km of an incinerator compared with national rates (SIR 1.04, 95% CI 1.02, 1.06), while Federico (2010) found an imprecise increase (i.e., a non-statistically significant result, yet an effect estimate greater than 1.00 and a confidence interval narrowly including the null value) of the SIR within 2 km compared with municipality rates (SIR 1.09, 95% CI 0.88, 1.34). Three studies reported mortality (García-Pérez et al., 2013; Romanelli et al., 2019; Salerno et al., 2015), none of which observed excess risks; the pooled estimate was null (1.05, 95% CI 0.95, 1.17; I^2 = 0.0%; Supplementary material Figure S1). Romanelli (2019) also found no association with hospitalizations.

For stomach cancer, only Elliot (1996) examined incidence, reporting a small excess risk within 3 km of an incinerator (SIR 1.05, 95% CI 1.03, 1.08). Three studies evaluated mortality (García-Pérez et al., 2013; Romanelli et al., 2019; Salerno et al., 2015); although García-Pérez (2013), Salerno (2015) and Romanelli (2019), in women, observed increased stomach mortality, these findings were not significant. The pooled mortality analysis showed no overall association (0.97, 95% CI 0.68, 1.36) with moderate heterogeneity (I^2 = 46.3%; Supplementary material Figure S3). Romanelli (2019) also assessed hospitalizations for stomach cancer and reported an increase, though not statistically significant, of the HR among women (HR 1.30, 95% CI 0.66, 2.56).

For liver cancer, four studies analysed incidence (Elliott et al., 1996; Goria et al., 2009; Mariné Barjoan et al., 2020; Reeve et al., 2013). Elliott (1996) observed a higher incidence within 3 km compared with national rates (SIR 1.13, 95% CI 1.05, 1.22), while Mariné Barjoan (2020) and Reeve (2013) did not detect excess risks. Goria (2009), which modelled exposure continuously, reported an imprecise association (adjusted coefficient 1.12, 95% CI −0.13, 2.37). The pooled estimate of the three studies with binary exposure definitions indicated no overall association (1.04, 95% CI 0.92, 1.18), with substantial heterogeneity (I^2 = 67.7%). Four studies assessed mortality (García-Pérez et al., 2013; Gouveia and Prado, 2010; Reeve et al., 2013; Romanelli et al., 2019), none of which observed significant associations; the pooled estimate was also null (1.05, 95% CI 0.92, 1.20; I^2 = 0.0%). Romanelli (2019) additionally found that, for hospitalizations, men showed an increase (though not statistically significant) in HR (1.11, 95% CI 0.69, 1.76).

Other hepatobiliary outcomes were less frequently reported. Federico (2010) examined liver and bile duct cancer incidence together and found no association, while Salerno (2015) observed increased mortality from liver and bile duct cancers (RR 2.10, 95% CI 1.35, 3.26. VoPham et al. (2022) investigated hepatocellular carcinoma incidence, comparing counties with estimated annual MSWI emissions > 2.31 g TEQ/year (Toxic Equivalents/year) to those with no emissions, and found no significant differences. García-Pérez (2013) assessed gallbladder cancer mortality and reported an imprecise increased risk (RR 1.24, 95% CI 0.98, 1.55). Except for Romanelli's cohort (Romanelli et al., 2019), all these studies followed an ecological design.

3.4.2. *Respiratory system*

Among respiratory system cancers, lung cancer was the most frequently studied. Three studies assessed incidence (Elliott et al., 1996; Mariné Barjoan et al., 2020; Reeve et al., 2013). Elliott (1996) reported a small excess within 3 km of an incinerator (SIR 1.08, 95% CI 1.07, 1.09), and Mariné Barjoan (2020) observed increased incidence in areas exposed to atmospheric fallout, but only among men (SIR 1.24, 95% CI 1.08, 1.41). The pooled analysis, however, did not confirm an overall association (1.05, 95% CI 0.93, 1.19), and heterogeneity was high (I^2 =

Table 4
Summary effect size (random-effect meta-analyses when no. of studies > 2) with 95% confidence interval (CI) of the association between high exposure to municipal solid waste incinerator emissions and type-specific cancers.

	Incidence				Mortality			
Type of cancer	N	Effect size	95% CI	I^2	N	Effect size	95% CI	I^2
Colorectal	2	-	-	-	3	1.05	0.95, 1.17	0.0%
Stomach	1	-	-	-	3	0.97	0.68, 1.36	46.3%
Liver	3	1.04	0.92, 1.18	67.7%	4	1.05	0.92, 1.20	0.0%
Lung	3	1.05	0.93, 1.19	81.8%	4	**1.17**	**1.03, 1.32**	21.3%
Breast	4	1.07	0.80, 1.44	69.0%	1	-	-	-
Leukaemia	2	-	-	-	3	1.28	0.91, 1.79	41.3%
Non-Hodgkin lymphoma	9	**1.20**	**1.00, 1.43**	84.8%	2	-	-	-
Soft tissue sarcoma	3	1.18	0.50, 2.76	82.0%	0	-	-	-

CI, Confidence Interval
Statistically significant values are presented in bold; some studies contributed more than one effect size (e.g., separate estimates for men and women)

81.8%).

Four studies investigated lung cancer mortality (García-Pérez et al., 2013; Gouveia and Prado, 2010; Romanelli et al., 2019; Salerno et al., 2015). García-Perez (2013) reported excess risk among residents within 5 km of an incinerator in Spain (RR 1.17, 95% CI 1.01, 1.34). Salerno (2015) also had significant results (RR 1.37, 95% CI 1.08, 1.74). The pooled analysis indicated a modest overall increase in lung cancer mortality (1.17, 95% CI 1.03, 1.32), with low heterogeneity ($I^2 = 21.3\%$; Fig. 2). Leave-one-out sensitivity analysis (Supplementary material Table S8) showed that the overall association was relatively stable across studies. The pooled effect remained elevated after sequential omission of individual studies, although statistical significance was lost when García-Pérez (2013), Gouveia e Prado (2010), or Salerno (2015) were excluded. Conversely, exclusion of Romanelli (2019), in the case of men, strengthened the association (1.22, 95% CI 1.09, 1.36). These patterns suggest a modest influence of individual study characteristics. Romanelli (2019) also examined hospitalizations and found an imprecise increased risk among women (HR 1.34, 95% CI 0.88, 2.05).

Other respiratory cancers were less frequently reported, all in ecological studies. Federico (2010) assessed lung, bronchus, and trachea incidence within 2 km of an incinerator; four studies investigated laryngeal cancer (Federico et al., 2010; Gouveia and Prado, 2010; Mariné Barjoan et al., 2020; Salerno et al., 2015); two examined pleural cancer (García-Pérez et al., 2013; Salerno et al., 2015); and only Mariné Barjoan (2020) specifically studied pleural mesothelioma. Some of these studies found evidence of an association, whereas others reported increased but non-significant risks for cancer incidence or mortality. More specifically, Mariné Barjoan (2020) found such a tendency among women for both larynx cancer (SIR 1.20, 95% CI 0.39, 2.80) and pleural mesothelioma (SIR 1.65, 95% CI 0.44, 4.21) incidence. Also, García-Pérez et al. (2013) found an increased risk (though imprecise) of pleural cancer mortality both among men and women (RR 1.55, 95% CI 0.94, 2.39), while Salerno et al. (2015) observed an imprecise increased risk for larynx cancer mortality in both sexes (RR 2.16, 95% CI 0.84, 5.51).

3.4.3. *Breast and gynaecological cancers*

Four studies on the incidence of breast cancer were eligible for the meta-analysis: one ecological (Mariné Barjoan et al., 2020), one case-control (Viel et al., 2008a), and two cohort studies (Rhee et al., 2023; VoPham et al., 2020). Viel (2008a) reported decreased odds of invasive breast cancer among women older than 60 years living in areas with high modelled ground-level concentrations (OR 0.31, 95% CI 0.08, 0.89), with no decrease among younger women (OR 0.88, 95% CI 0.43, 1.79). VoPham et al. (2020) observed a higher incidence of invasive breast cancer among women residing in counties with annual MSWI emissions greater than 2.31 g TEQ/year compared with counties without emissions (HR 1.39, 95% CI 1.00, 1.93). Rhee et al. (2023) detected an imprecise increase of the HR among women (HR 1.50, 95% CI 0.98, 2.29). Mariné Barjoan et al. (2020) did not detect associations with exposure. When pooled, these incidence studies showed no overall association (1.07, 95% CI 0.80, 1.44), with substantial heterogeneity ($I^2 = 69.0\%$). Two additional studies used continuous exposure definitions and were, therefore, not included in the meta-analysis: Goria (2009), ecological, reported an adjusted coefficient of 0.69 (95% CI 0.23, 1.14) based on average cumulative ground-level dioxin deposits, and Praud et al. (2025), a nested case-control study, reported an adjusted OR of 1.03 (95% CI 0.99, 1.07) per 7.4 μg -TEQ/m^2 increment. Breast cancer mortality was investigated in an ecological study by Salerno (2015), which did not find an association; no mortality pooling was performed.

Reproductive cancers were less frequently studied, all in ecological designs. García-Pérez (2013) and Salerno (2015) examined ovarian cancer mortality, and the former reported an imprecise increase in risk (RR 1.13, 0.95, 1.34 and RR 1.03, 95% CI 0.50, 2.12, respectively). Salerno (2015) also investigated uterine cancer mortality (RR 1.48, 95% CI 0.63, 3.48), and García-Pérez (2013) evaluated vulvar and vaginal cancer mortality (RR 1.01, 95% CI 0.70, 1.40).

3.4.4. *Hematologic and lymphatic system*

For the hematologic and lymphatic system, NHL was the most frequently investigated cancer type. Incidence was examined in nine studies: six ecological (Elliott et al., 1996; Federico et al., 2010; Mariné Barjoan et al., 2020; Reeve et al., 2013; Viel et al., 2008b, 2000), two case-control (Floret et al., 2003; Pronk et al., 2013), and one cohort (Fisher et al., 2024). Findings were heterogeneous. Elliot (1996) and Viel (2000) reported increased incidence closer to incinerators (SIR 1.03, 95% CI 1.00, 1.07; and SIR 1.84, 95% CI 1.51, 2.23, respectively), Floret (2003) observed elevated odds in areas of higher modelled dioxin concentration (OR 2.30, 95% CI 1.40, 3.80) and Viel (2008b) found increased risk among residents of census blocks with cumulative ground-level concentrations in the 90th percentile (RR 1.12, 95% CI 1.00, 1.25). In contrast, Federico (2010), Reeve (2013), and Pronk (2013), all based on residential proximity, did not report significant associations. As shown in Fig. 3, the pooled analysis indicated excess risk of NHL incidence associated with incinerator exposure (1.20, 95% CI 1.00, 1.43; $I^2 = 84.8\%$). Leave-one-out sensitivity analysis (Supplementary material Table S10) showed that the pooled RR remained > 1.0 across all scenarios, but statistical significance was lost

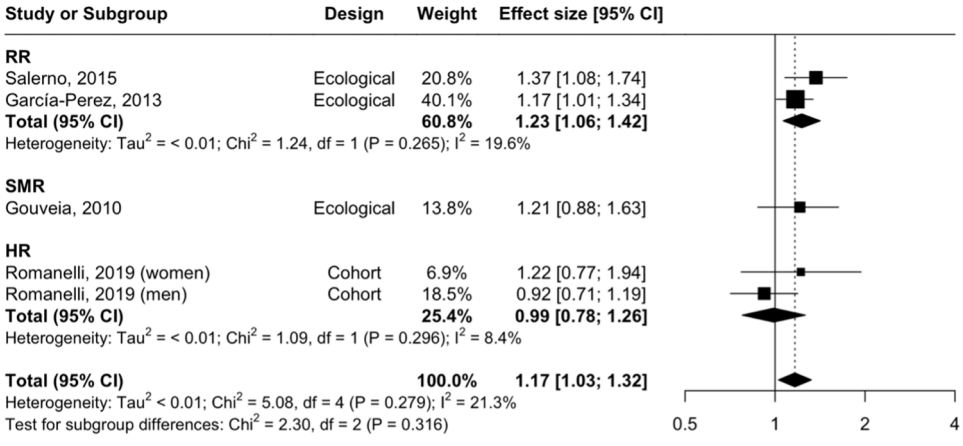


Fig. 2. Forest plot of the association between exposure to municipal solid waste incinerators and lung cancer mortality. Individual study estimates are shown by effect size type (relative risk [RR], standardized mortality ratio [SMR], and hazard ratio [HR]) with 95% confidence intervals, along with pooled estimates within each subgroup and overall. CI, confidence interval; DF, degrees of freedom; HR, hazard ratio; RR, relative risk; SMR, standardized mortality ratio.

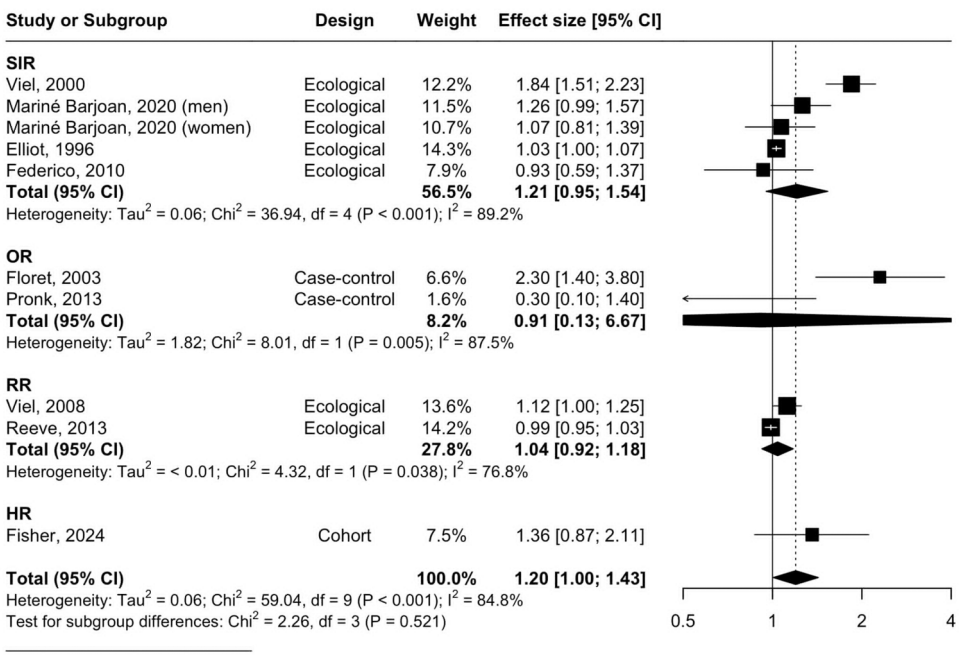


Fig. 3. Forest plot of the association between exposure to municipal solid waste incinerators and non-Hodgkin lymphoma incidence. Individual study estimates are shown by effect size type (relative risk [RR], odds ratio [OR], standardized incidence ratio [SIR], and hazard ratio [HR]) with 95% confidence intervals, along with pooled estimates within each subgroup and overall. CI, confidence interval; DF, degrees of freedom; HR, hazard ratio; RR, relative risk; SMR, standardized mortality ratio; OR, odds ratio.

when Floret (2003), Mariné Barjoan (2020), Viel (2008b), Viel (2000), or Fisher (2024) were excluded. Excluding Viel (2000) produced the greatest attenuation (1.08, 95% CI 0.99, 1.18; $I^2 = 66\%$). Overall, the association is sensitive to multiple individual investigations, rather than being driven by a single study. Romanelli (2019) assessed NHL mortality and hospitalizations and found an non-statistically significant HR increase in both sexes.

Other lymphatic malignancies were less frequently investigated. Gouveia and Prado (2010) and Salerno (2015), both ecological studies, examined lymphoma mortality. The latter found increased risk (RR 2.43, 95% CI 1.09, 5.40). Elliot (1996) assessed the incidence of lymphatic and hematopoietic tissues combined and reported no association. Romanelli (2019) also evaluated mortality and hospitalizations from lymphatic and hematopoietic tissues, with most estimates suggesting increased risks, although not statistically significant. One exception was found for mortality among men residing in areas with high modelled exposure, regarding which a higher risk was observed ($NO\chi$-MWI or Municipal Waste Incineration related $NO\chi > 0.03$ μg/m^3; HR 1.79, 95% CI 1.03, 3.12).

Regarding leukaemia in the adult population, incidence was investigated in two ecological studies (Federico et al., 2010; Reeve et al., 2013). Reeve (2013) reported an increased relative risk among residents living within 10 km of an incinerator (RR 1.14, 95% CI 1.07, 1.21), whereas Federico (2010) observed a non-significant increase (SIR 1.14, 95% CI 0.66, 1.82). Three ecological studies assessed leukaemia mortality (García-Pérez et al., 2013; Romanelli et al., 2019; Salerno et al., 2015), with non-significant results in all of them. In the pooled analysis of mortality, the summary estimate suggested an imprecise association (1.28, 95% CI 0.91, 1.79; $I^2 = 41.3\%$). Leave-one-out sensitivity analysis (Supplementary material Table S11) indicated that results were somewhat unstable: exclusion of García-Pérez (2013) yielded a statistically significant association (RR 1.61, 95% CI 1.05, 2.46), while omission of the other studies maintain an overall effect size greater than one, but not statistically significant. Mariné Barjoan (2020) examined acute myeloid leukaemia incidence and found increased, but not significant, risk among women (SIR 1.46, 95% CI 0.73, 2.61).

For other hematologic malignancies, Mariné Barjoan (2020) investigated multiple myeloma incidence and reported an excess among men living in areas exposed to atmospheric fallout from the incinerator plume (SIR 1.76, 95% CI 1.21, 2.47), but not among women. Salerno (2015) examined multiple myeloma mortality and found no association. Mariné Barjoan (2020) also evaluated myelodysplastic and myeloproliferative syndromes, observing a higher risk (non-significant) for myeloproliferative syndromes in women (SIR 1.54, 95% CI 0.93, 2.41).

3.4.5. *Other cancer types*

Bladder cancer was the most frequently examined urinary tract outcome. Two ecological studies investigated incidence (Elliott et al., 1996; Mariné Barjoan et al., 2020) and two reported mortality (García-Pérez et al., 2013; Salerno et al., 2015). Elliott et al. (1996) and Mariné Barjoan et al. (2020) found no evidence of increased risk associated with incinerator exposure; García-Perez et al. (2013) and Salerno et al. (2015) found imprecise, though higher mortality risk for both sexes (RR 1.13, 95% IC 0.95, 1.34 and RR 1.62, 95% CI 0.85, 3.07). Kidney/renal cancer mortality was assessed in two ecological studies (García-Pérez et al., 2013; Salerno et al., 2015), both with non-significant estimates.

Three ecological studies investigated soft tissue sarcoma incidence in adults (Federico et al., 2010; Mariné Barjoan et al., 2020; Viel et al., 2000). Viel (2000) reported an excess incidence in areas closer to the incinerator (SIR 3.44, 95% CI 1.77, 6.01), whereas Federico (2010) and Mariné Barjoan (2020) found no associations. When combined, these studies showed no overall association (RR 1.18, 95% CI 0.50, 2.76), with substantial heterogeneity ($I^2 = 82.0\%$). García-Perez (2013) and Romanelli (2019), an ecological and a cohort study, respectively, assessed mortality from connective tissue and other soft tissue cancers and found no differences. Romanelli (2019) also examined hospitalizations and reported no association. Elliot (1996) investigated connective tissue cancer incidence and likewise did not observe differences.

Two ecological studies examined mortality from cancers of the nervous system. Salerno (2015) assessed nervous system cancers broadly, while García-Perez (2013) focused specifically on brain cancer. The former reported an imprecise increase in RR (1.75, 95% CI 0.88, 3.47)

and the latter a marginal effect (RR 0.99, 95% CI 0.84, 1.16). Finally, García-Perez (2013) assessed thyroid and skin cancer mortality and found no differences in risk between residents living within 5 km of the incinerator and those living further away. For skin cancer, a non-significant increase in RR (RR 1.12, 95% 0.71, 1.66) was found.

3.4.6. All cancers

Four ecological studies investigated the incidence of all cancer types altogether (Elliott et al., 1996; Federico et al., 2010; Goria et al., 2009; Mariné Barjoan et al., 2020) and one assessed all oncological mortality (García-Pérez et al., 2013). Elliot (1996) identified a small, although highly precise, excess incidence within 3 km of an incinerator (SIR 1.04, 95% CI 1.03, 1.04), while Goria (2009) reported an adjusted coefficient of 0.67 (95% CI 0.37, 0.97) among women. Mariné Barjoan (2020) observed a lower incidence among women (SIR 0.93, 95% CI 0.89, 0.98) and for all cancers excluding skin (SIR 0.94, 95% CI 0.89, 0.99). Federico (2010) did not report significant differences. García-Perez (2013) found a modest increase in overall cancer mortality risk (RR 1.09, 95% CI 1.01, 1.18).

3.5. Reporting biases

Funnel plots were examined for each meta-analysis (provided in the supplementary material). For NHL incidence (n = 9 studies; 10 effect estimates), Egger's regression test showed no evidence of small-study effects (t = 1.54, df = 8, bias = 1.55 [SE 1.00], p = 0.16). However, the relatively small number of included studies limits the power of this test to detect small-study effects. For all other outcomes, the number of contributing studies was too small to allow a reliable assessment of funnel plot asymmetry, and visual inspection of the plots should be interpreted with caution.

3.6. Certainty of evidence

Considering the five GRADE domains, and since all studies followed an observational design, the considered cancer outcomes were downgraded, ranging from low (breast cancer) to very low (all the other cancers) (Table 5). Firstly, pooled relative risks were often close to one, with confidence intervals presenting no effect, emphasizing uncertainty. Moreover, several studies showed methodological weaknesses (uncontrolled confounding, crude exposure measures) and inconsistent results (heterogeneity). Finally, publication bias could not be confirmed due to an insufficient number of studies, thus contributing to the overall uncertainty of the evidence.

4. Discussion

This systematic review and meta-analysis aimed to synthesise the available information about the association between exposure to MSWI and risk of cancer in human populations. We chose to focus only on MSWI to reduce heterogeneity related to different types of waste and technologies. This narrow scope allowed for a more coherent synthesis of the available evidence on different cancer-related outcomes. Nevertheless, it is important to note that the broad temporal scope of this review (1996–January 2025) poses challenges for result interpretation, as the composition of municipal solid waste has evolved over time, with an increasing proportion of contaminated plastics being incinerated (Rogers and Jaspers, 2025). In addition, incinerator technologies, as well as regulatory contexts about emissions, changed over this period, further challenging the interpretation of results. Combining studies of different time periods, incinerator types, and technical features (e.g., plant age, waste composition) may introduce a potential aggregation bias and underestimate health effects (Baek et al., 2022).

In our analysis, when considering the different cancer types, risk estimates for liver, stomach, and colorectal cancers were generally null or near-null, while NHL showed the clearest indication of potential increased risk (incidence). The previous evidence on the increased risk of NHL with exposure to incinerators is mixed: Baek et al. (2022) found a non-significant pooled effect estimate for NHL incidence, while also referring that although some individual studies reported elevated risks, the overall evidence was inconsistent, with some investigations even reporting significantly lower risks in specific populations. In contrast, individual studies, mainly from older facilities, have reported elevated risks (Floret et al., 2003; Viel et al., 2000), more in line with the results observed in our study. This largely relies on the wide disparities between the studies, namely in terms of generation of the facilities with different emission levels (old generation incinerators with elevated levels of emissions vs. new generation incinerators with reduced levels) and the methodological specificities of the studies themselves (Baek et al., 2022; Floret et al., 2003; Negri et al., 2020; Viel et al., 2000). Although not the only chemicals involved (Kachuri et al., 2020), the increased risk of NHL is often associated with the dioxins emitted by incinerators. There is epidemiological evidence on the link between some dioxin-like compounds and cancer risk (namely, NHL) in humans (Cole et al., 2003; Franchini et al., 2004; Pesatori et al., 2009; Steenland et al., 2004). Dioxins, by persistently binding to the cytosolic AhR receptor, trigger lasting changes in gene expression in xenobiotic metabolism, inflammation, oxidative stress, hormonal signalling, and cell cycle control pathways, promoting tumour initiation and growth (Furue et al., 2021; Kachuri et al., 2020; Viel et al., 2008a; VoPham et al., 2020).

Table 5
GRADE assessment of certainty of evidence for cancer outcomes (no. of studies > 2).

Cancer outcome	No. of studies	No. of participants	Summary effect (95% CI)	Certainty	Reasons for downgrading
Colorectal (mortality)	3	147 993	1.05 (0.95, 1.17)	Very low	Observational design, risk of bias, imprecision, and inconsistent results
Stomach (mortality)	3	147 993	0.97 (0,68, 1.36)	Very low	Observational design, risk of bias, imprecision, and inconsistent results
Liver (incidence)	3	4 659 476	1.04 (0.92, 1.18)	Very low	Ecological bias in most studies, lack of confounder control, and imprecision
Liver (mortality)	4	782 986	1.05 (0.92, 1.20)	Very low	
Lung (incidence)	3	4 659 476	1.05 (0.93, 1.19)	Very low	Bias in exposure assessment, heterogeneity, and imprecision
Lung (mortality)	4	782 986	1.17 (1.03, 1.32)	Very low	
Breast (incidence)	4	1 245 327	1.07 (0.80, 1.44)	Low	Risk of bias, heterogeneity, and imprecision
Leukaemia (mortality)	3	240 887	1.28 (0.91, 1.79)	Very low	Observational design, bias, imprecision, despite low heterogeneity
Non-Hodgkin lymphoma (incidence)	9	5 119 823	1.20 (1.00, 1.43)	Very low	Risk of bias, heterogeneity, and imprecision across study designs
Soft tissue sarcoma (incidence)	3	1 259 586	1.18 (0.50, 2.76)	Very low	Wide confidence intervals, risk of bias

CI, Confidence Interval
Number of participants was calculated as the total population/participants analysed in cohort and ecological studies, and as cases plus controls in case-control studies. For studies where only the number of cases was reported, the available case count was included and the denominator was considered not fully reported.

This meta-analysis also found a statistically significant, though modest, association between exposure to MSWI and lung cancer mortality, with a relatively consistent direction of effect. This result is in line with previous studies that identified excess risks associated with first-generation incinerators, operating in periods with less stringent regulations and potentially higher emission levels (Biggeri et al., 1996; Elliott et al., 1996; Franchini et al., 2004). However, similarly to other cancer types, no consistent global excess has emerged in analyses that pooled data, or in investigations of more recent (second-generation) facilities (Ancona et al., 2015; Baek et al., 2022; Michelozzi et al., 1998; Parodi et al., 2004). Lung cancer has been associated with pollutants emitted by incinerators, such as particulate matter (and air pollution in general) and heavy metals such as cadmium, arsenic, and chromium (Baek et al., 2022; Negri et al., 2020).

Evidence for other cancer types was largely null and/or highly heterogeneous. For lung cancer, incidence estimates were close to null with substantial between-study variability, contrasting with the mortality data, an inconsistency that may reflect differences in study design, exposure metrics, outcome ascertainment, or residual confounding rather than a true divergence in risk. Breast cancer incidence likewise showed no clear pooled association. For leukaemia mortality and soft tissue sarcoma incidence, pooled effects were not statistically significant, but sensitivity analyses indicated that results could have been influenced by individual studies, underscoring the weakness of the available evidence base. Lastly, for less frequently assessed sites (e.g., urinary, thyroid, skin, CNS), pooled estimates were generally near the null (based on few studies). Overall, these patterns reinforce that, outside a small number of signals, the current literature remains sparse, methodologically heterogeneous, and insufficient to draw robust causal inferences regarding residential exposure to MSWI emissions.

The body of evidence included in our review reflects a wide range of study designs, methodological quality, and exposure assessment approaches, all of which influence the interpretation of the observed associations. First, the predominance of studies with an observational design—i.e., ecological studies, which are more susceptible to exposure misclassification and confounding, hampering the identification of parameters of interest at the individual level (Negri et al., 2020)—played a pivotal role in the assessment of a lower strength of findings. In contrast, more robust evidence emerged from cohort and case-control studies, with higher methodological quality, particularly in relation to studies on breast cancer (e.g., VoPham et al., 2020), where greater certainty was reached. This weakness in confidence of findings' interpretation due to heterogeneity in design and reliance on poorer methodologies has been noted in previous reviews (Bottini et al., 2025; Tait et al., 2020). By relying mainly on aggregate exposure proxies, such as residential distance to incinerators and dispersion models, ecological studies do not directly assess individual risk factors nor specific environmental factors (Comba et al., 2003; Franchini et al., 2004; Healy and Gilliland, 2012; Morgenstern, 1995; Roumeliotis et al., 2021). Moreover, the use of distinct exposure assessment methods introduces heterogeneity in exposure categorization, hindering comparability across studies and biasing results (Baek et al., 2022; Negri et al., 2020).

The observed effect estimates were mostly modest, with wide confidence intervals, reflecting statistical imprecision. This highlights the need to conduct more rigorous studies with stronger designs and individual-level data, given the importance, from a public health perspective, of detecting small variations in cancer risk over time. Through mapping the exposome, the totality of environmental exposures—including lifestyle factors—from the prenatal period onward, researchers want to fill critical gaps in our ability to comprehensively study the environmental (non-genetic) drivers of disease (European Parliament. Directorate General for Parliamentary Research Services., 2025). An important methodological limitation of the analysed evidence in this review was the frequent co-location of MSWI with other industrial pollution sources, such as landfills, power plants, and refineries, as well as with agricultural land, among others. As discussed in previous studies, even in those that attempted to adjust for co-exposures, this spatial clustering potentially hinders exposure assessment, thus limiting the possibility to directly establish causal attributions between the observed health effects, specifically, and MSWI emissions (Baek et al., 2022; Franchini et al., 2004; Knox, 2000; Negri et al., 2020).

Although this study represents a step forward compared to previous reviews in the field, some limitations need to be addressed. This review was restricted to English-language publications, which may have led to the omission of relevant evidence published in other languages. Also, to reduce heterogeneity between study methods, the results were analysed solely from MSWI, thus assuring a more targeted evaluation of cancer risks. Yet, it included research extending over a period of almost three decades of publications, encompassing cancer cases from the mid-1970s to 2018, with exposure assessments covering earlier decades. This extended period covers several technological and regulatory changes (transition from first to second and third generation) with resulting reduction in emissions, which may have mitigated the risk of cancer. Furthermore, the latency period of the disease makes it difficult to draw firm conclusions about more modern plants. An additional limitation of this review concerns the inclusion of studies with different designs. As previously noted, among observational studies, ecological designs are generally considered to provide weaker epidemiological evidence due to their reliance on group-level data and limited ability to control confounding. The focus on MSWI restricted the pool of eligible study designs. The pooled analysis of different effect measures (RR, OR, HR and SMR/SIR), whose underlying assumptions and statistical interpretation do not fully overlap, can also have contributed to more heterogeneity and introduce potential bias (Greenland and O'Rourke, 2008; Higgins et al., 2024). Since relying on different measures of association may have made pooled results less precise and informative, we sought to minimize this limitation by conducting subgroup analysis according to effect measure. More importantly, we aimed to prioritize methodological rigor by clearly describing study characteristics and assessing study quality, and we gave particular attention to findings from higher-quality designs, such as cohort and case-control studies, when interpreting the overall evidence. Moreover, we were unable to conduct the planned stratified analyses by study quality, exposure assessment method, or exposure duration, to explore potential sources of heterogeneity. This was not possible to implement due to the limited number of eligible studies reporting comparable data across these variables. Finally, the reduced number of studies in this review may have had additional implications for the assessment of the publication bias. This is related to the fact that publications reporting positive associations are more likely to be published (Mlinarić et al., 2017; Song et al., 2010), which might have led to an overestimation of the true effect.

5. Conclusion

This systematic review and meta-analysis entail a focused synthesis of the available epidemiological evidence on the association between cancer risk and exposure to MSWI, thereby improving the specificity of the exposure context. Among the cancer types evaluated, non-Hodgkin lymphoma incidence showed the most consistent evidence of an elevated risk, though with a very low level of certainty.

Future research in this area would benefit substantially from stronger epidemiological designs and clearer targets of inference. The predominance of ecological studies in this field has long been recognized as a key limitation, mainly due to exposure misclassification, residual confounding, and the inability to address individual-level risk factors. Large population-based cohort studies and well-designed case–control investigations, incorporating detailed residential histories and individual covariates such as smoking, socioeconomic status, and occupational exposures, are therefore needed. Greater harmonization of exposure definitions (particularly regarding distance metrics, exposure windows, and latency assumptions) would also improve comparability across

studies. In addition, explicit consideration of co-location with other industrial sources remains essential, as spatial clustering of multiple pollution sources can bias effect estimates if not adequately addressed.

Progress in this field will also depend on more refined exposure assessment strategies, as residential proximity alone is unlikely to capture the complexity and temporal variability of MSWI-related exposures. Integrating emissions inventories, dispersion modelling, and environmental or biological monitoring data, together with coordinated multi-site studies, would improve exposure characterization, increase statistical power, and strengthen the public health relevance of future findings.

CRediT authorship contribution statement

Tommaso Filippini: Writing – review & editing, Validation, Methodology, Conceptualization. **Jurgen Buekers:** Writing – review & editing, Validation, Supervision, Resources, Methodology, Funding acquisition, Conceptualization. **Ana Virgolino:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Resources, Project administration, Methodology, Investigation, Funding acquisition, Data curation, Conceptualization. **Mónica Fialho:** Writing – review & editing, Visualization, Software, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Raquel Martins:** Writing – review & editing, Validation, Investigation, Conceptualization. **Osvaldo Santos:** Writing – review & editing, Validation, Supervision, Resources, Methodology, Investigation, Funding acquisition, Data curation, Conceptualization. **Carolina Capitão:** Writing – review & editing, Writing – original draft, Visualization, Validation, Project administration, Methodology, Investigation, Conceptualization. **Anthony Purece:** Writing – review & editing, Validation, Supervision, Resources, Methodology, Funding acquisition, Conceptualization. **Murilo Engel:** Writing – review & editing, Validation, Conceptualization. **Ricardo R. Santos:** Writing – review & editing, Investigation, Conceptualization. **Rodrigo Feteira-Santos:** Writing – review & editing, Investigation, Conceptualization.

Funding statement

This work was developed under the European Partnership for the Assessment of Risks from Chemicals (PARC) and has received funding from the European Union's Horizon Europe research and innovation program under Grant Agreement Nº 101057014.

Funding sources/sponsors

This work was carried out in the framework of the European Partnership for the Assessment of Risks from Chemicals (PARC) and has received funding from the European Union's Horizon Europe research and innovation programme under Grant Agreement No 101057014. Views and opinions expressed are, however, those of the authors only and do not necessarily reflect those of the European Union or the Health and Digital Executive Agency. Neither the European Union nor the granting authority can be held responsible for them.

Registration

This review is registered in PROSPERO (CRD42024526207).

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.etap.2026.105078.

Data availability

Data are all available (body text and supplementary material). Meta-analysis code is available at ZENODO (link to be included at production phase of the paper).

References

Ancona, C., Badaloni, C., Mataloni, F., Bolignano, A., Bucci, S., Cesaroni, G., Sozzi, R., Davoli, M., Forastiere, F., 2015. Mortality and morbidity in a population exposed to multiple sources of air pollution: a retrospective cohort study using air dispersion models. Environ. Res. 137, 467–474. https://doi.org/10.1016/j.envres.2014.10.036.

Atkins, D., Best, D., Eccles, M., Falck-Ytter, Y., Flottorp, S., Guyatt, G.H., Harbour, R.T., Haugh, M.C., Henry, D., Hill, S., Jaescjke, R., Leng, G., Liberati, A., Magrini, N., Mason, J., Middleton, P., Mrukowicz, J., O'Connell, D., Oxman, A.D., Phillips, B., Schünemann, H.J., Edejer, T.T.-T., Varonen, H., Vist, G.E., Williams Jr, J.V., Zaza, S., GRADE Working Group, 2004. Grading quality of evidence and strength of recommendations. BMJ 328, 1490. https://doi.org/10.1136/bmj.328.7454.1490.

Baek, K., Park, J.-T., Kwak, K., 2022. Systematic review and meta-analysis of cancer risks in relation to environmental waste incinerator emissions: a meta-analysis of case-control and cohort studies. Epidemiol. Health 44. https://doi.org/10.4178/epih.e2022070.

Balduzzi, S., Rücker, G., Schwarzer, G., 2019. How to perform a meta-analysis with R: a practical tutorial. Evid. Based Ment. Health 22, 153–160. https://doi.org/10.1136/ebmental-2019-300117.

Barone, E., Corrado, A., Gemignani, F., Landi, S., 2016. Environmental risk factors for pancreatic cancer: an update. Arch. Toxicol. 90, 2617–2642. https://doi.org/10.1007/s00204-016-1821-9.

Biggeri, A., Barbone, F., Lagazio, C., Bovenzi, M., Stanta, G., 1996. Air pollution and lung cancer in Trieste, Italy: spatial analysis of risk as a function of distance from sources. Environ. Health Perspect. 104, 750–754. https://doi.org/10.1289/ehp.96104750.

Bottini, I., Vecchi, S., De Sario, M., Bauleo, L., Trentalange, A., Michelozzi, P., Ancona, C., 2025. Residential exposure to municipal solid waste incinerators and health effects: a systematic review with meta-analysis. BMC Public. Health 25, 1989. https://doi.org/10.1186/s12889-025-23150-z.

Carpenter, D.O., Arcaro, K., Spink, D.C., 2002. Understanding the human health effects of chemical mixtures. Environ. Health Perspect. 110, 25–42. https://doi.org/10.1289/ehp.02110s125.

Cole, P., Trichopoulos, D., Pastides, H., Starr, T., Mandel, J.S., 2003. Dioxin and cancer: a critical review. Regul. Toxicol. Pharmacol. 38, 378–388. https://doi.org/10.1016/j.yrtph.2003.08.002.

Comba, P., Ascoli, V., Belli, S., Benedetti, M., Gatti, L., Ricci, P., Tieghi, A., 2003. Risk of soft tissue sarcomas and residence in the neighbourhood of an incinerator of industrial wastes. Occup. Environ. Med. 60, 680–683. https://doi.org/10.1136/oem.60.9.680.

Cordioli, M., Ranzi, A., De Leo, G.A., Lauriola, P., 2013. A review of exposure assessment methods in epidemiological studies on incinerators. J. Environ. Public. Health 2013, 129470. https://doi.org/10.1155/2013/129470.

Directive (EU), 2010. 2010/75/EU of the European Parliament and of the Council of 24 November 2010, on industrial emissions (integrated pollution prevention and control). Off. J. Eur. Union. 334, 17–119.

Directive (EU), 2018. 2018/851 of the European Parliament and of the Council of 30 May 2018, amending Directive 2008/98/EC on waste. Off. J. Eur. Union. 150/110, 109–140.

Duan, W., Xu, C., Liu, Q., Xu, J., Weng, Z., Zhang, X., Basnet, T.B., Dahal, M., Gu, A., 2020. Levels of a mixture of heavy metals in blood and urine and all-cause, cardiovascular disease and cancer mortality: A population-based cohort study. Environ. Pollut. 263, 114630. https://doi.org/10.1016/j.envpol.2020.114630.

Egger, M., Smith, G.D., Schneider, M., Minder, C., 1997. Bias in meta-analysis detected by a simple, graphical test. BMJ 315, 629–634. https://doi.org/10.1136/bmj.315.7109.629.

Elliott, P., Shaddick, G., Kleinschmidt, I., Jolley, D., Walls, P., Beresford, J., Grundy, C., 1996. Cancer incidence near municipal solid waste incinerators in Great Britain. Br. J. Cancer 73, 702–710. https://doi.org/10.1038/bjc.1996.122.

European Commission, 2021. Pathway to a healthy planet for all. EU action plan: towards zero pollution for air, water and soil. Brussels.

European Environment Agency, 2025. Circular economy [WWW Document]. URL ⟨https://www.eea.europa.eu/en/topics/in-depth/circular-economy⟩ (accessed 1.12.26).

European Parliament. Directorate General for Parliamentary Research Services., 2025. Human exposome research: potentials, limitations and public policy implications. Publications Office, LU.

Federico, M., Pirani, M., Rashid, I., Caranci, N., Cirilli, C., 2010. Cancer incidence in people with residential exposure to a municipal waste incinerator: An ecological study in Modena (Italy), 1991–2005. Waste Management, IWWG Task Group on "Thermal Treatments" 30, 1362–1370. https://doi.org/10.1016/j.wasman.2009.06.032.

Fisher, J.A., Medgyesi, D.N., Deziel, N.C., Nuckols, J.R., Ward, M.H., Jones, R.R., 2024. Residential proximity to dioxin-emitting facilities and risk of non-Hodgkin lymphoma in the NIH-AARP Diet and Health Study. Environ. Int. 188, 108767. https://doi.org/10.1016/j.envint.2024.108767.

Floret, N., Mauny, F., Challier, B., Arveux, P., Cahn, J., Viel, J., 2003. Dioxin emissions from a solid waste incinerator and risk of non-Hodgkin lymphoma. Epidemiology 14, 392–398.

Franchini, M., Rial, M., Buiatti, E., Bianchi, F., 2004. Health effects of exposure to waste incinerator emissions:a review of epidemiological studies. Ann. Ist. Super. Sanit. à 40, 101–115.

Furue, M., Ishii, Y., Tsukimori, K., Tsuji, G., 2021. Aryl Hydrocarbon Receptor and Dioxin-Related Health Hazards—Lessons from Yusho. IJMS 22, 708. https://doi.org/10.3390/ijms22020708.

García-Pérez, J., Fernández-Navarro, P., Castelló, A., López-Cima, M.F., Ramis, R., Boldo, E., López-Abente, G., 2013. Cancer mortality in towns in the vicinity of incinerators and installations for the recovery or disposal of hazardous waste. Environ. Int. 51, 31–44. https://doi.org/10.1016/j.envint.2012.10.003.

Ghisellini, P., Cialani, C., Ulgiati, S., 2016. A review on circular economy: the expected transition to a balanced interplay of environmental and economic systems. J. Clean. Prod. 114, 11–32. https://doi.org/10.1016/J.JCLEPRO.2015.09.007.

González, N., Cunha, S.C., Monteiro, C., Fernandes, J.O., Marquès, M., Domingo, J.L., Nadal, M., 2019. Quantification of eight bisphenol analogues in blood and urine samples of workers in a hazardous waste incinerator. PubMed 176, 108576.

Goria, S., Daniau, C., De Crouy-Chanel, P., Empereur-Bissonnet, P., Fabre, P., Colonna, M., Duboudin, C., Viel, J.-F., Richardson, S., 2009. Risk of cancer in the vicinity of municipal solid waste incinerators: importance of using a flexible modelling strategy. Int. J. Health Geogr. 8, 31. https://doi.org/10.1186/1476-072X-8-31.

Gouveia, N., Prado, R.R.D., 2010. Análise espacial dos riscos à saúde associados à incineração de resíduos sólidos: avaliação preliminar. Rev. Bras. Epidemiol. 13, 3–10. https://doi.org/10.1590/S1415-790X2010000100001.

Greenland, S., O'Rourke, K., 2008. Meta-analysis, in: Modern Epidemiology. Philadelphia, pp. 682–685.

Healy, M.A., Gilliland, J.A., 2012. Quantifying the magnitude of environmental exposure misclassification when using imprecise address proxies in public health research. Spat. Spatio-Tempo Epidemiol. 3, 55–67. https://doi.org/10.1016/j.sste.2012.02.006.

Higgins, J., Thomas, J., Chandler, J., Cumpston, M., Li, T., Page, M., Welch, V., 2024. Cochrane Handbook for Systematic Reviews of Interventions version 6.5 (updated August 2024).

International Agency for Research on Cancer, 2012. Arsenic, metals, fibres, and dusts. Volume 100C. A review of human carcinogens, IARC Monographs on the Evaluation of Carcinogenic Risks to Humans. Lyon, France.

Kachuri, L., Beane Freeman, L.E., Spinelli, J.J., Blair, A., Pahwa, M., Koutros, S., Hoar Zahm, S., Cantor, K.P., Weisenburger, D.D., Pahwa, P., Dosman, J.A., McLaughlin, J. R., Demers, P.A., Harris, S.A., 2020. Insecticide use and risk of non-Hodgkin lymphoma subtypes: A subset meta-analysis of the North American Pooled Project. Int. J. Cancer 147, 3370–3383. https://doi.org/10.1002/ijc.33164.

Kafle, S., Karki, B.K., Sakhakarmy, M., Adhikari, S., 2025. A review of global municipal solid waste management and valorization pathways. Recycling 10, 113. https://doi.org/10.3390/recycling10030113.

Kalmykova, Y., Sadagopan, M., Rosado, L., 2018. Circular economy – From review of theories and practices to development of implementation tools. Resour. Conserv. Recycl. Sustain. Resour. Manag. Circ. Econ. 135, 190–201. https://doi.org/10.1016/j.resconrec.2017.10.034.

Knox, E., 2000. Childhood cancers, birthplaces, incinerators and landfill sites. Int. J. Epidemiol. 29, 391–397.

Laureti, L., Costantiello, A., Anobile, F., Leogrande, A., Magazzino, C., 2024. Waste management and innovation: Insights from Europe. Recycling 9, 82. https://doi.org/10.3390/recycling9050082.

Mariné Barjoan, E., Doulet, N., Chaarana, A., Festraëts, J., Viot, A., Ambrosetti, D., Lasalle, J.-L., Mounier, N., Bailly, L., Pradier, C., 2020. Cancer incidence in the vicinity of a waste incineration plant in the Nice area between 2005 and 2014. Environ. Res. 188, 109681. https://doi.org/10.1016/j.envres.2020.109681.

Michelozzi, P., Fusco, D., Forastiere, F., Ancona, C., Dell'Orco, V., Perucci, C.A., 1998. Small area study of mortality among people living near multiple sources of air pollution. Occup. Environ. Med. 55, 611–615. https://doi.org/10.1136/oem.55.9.611.

Mlinarić, A., Horvat, M., Šupak Smolčić, V., 2017. Dealing with the positive publication bias: Why you should really publish your negative results. Biochem. Med. 27, 030201. https://doi.org/10.11613/BM.2017.030201.

Morgenstern, H., 1995. Ecologic Studies in Epidemiology: Concepts, Principles, and Methods. Annu. Rev. Public. Health 16, 61–81. https://doi.org/10.1146/annurev.pu.16.050195.000425.

National Institutes of Health, 2014. Quality assessment tool for observational cohort and cross-sectional studies.

Negri, E., Bravi, F., Catalani, S., Guercio, V., Metruccio, F., Moretto, A., La Vecchia, C., Apostoli, P., 2020. Health effects of living near an incinerator: A systematic review of epidemiological studies, with focus on last generation plants. Environ. Res. 184, 109305. https://doi.org/10.1016/j.envres.2020.109305.

Page, M.J., McKenzie, J.E., Bossuyt, P.M., Boutron, I., Hoffmann, T.C., Mulrow, C.D., Shamseer, L., Tetzlaff, J.M., Akl, E.A., Brennan, S.E., Chou, R., Glanville, J., Grimshaw, J.M., Hróbjartsson, A., Lalu, M.M., Li, T., Loder, E.W., Mayo-Wilson, E., McDonald, S., McGuinness, L.A., Stewart, L.A., Thomas, J., Tricco, A.C., Welch, V.A., Whiting, P., Moher, D., 2021. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. BMJ 372. https://doi.org/10.1136/bmj.n71.

Parodi, S., Baldi, R., Benco, C., Franchini, M., Garrone, E., Vercelli, M., Pensa, F., Puntoni, R., Fontana, V., 2004. Lung Cancer Mortality in a District of La Spezia (Italy) Exposed to Air Pollution from Industrial Plants. Tumori 90, 181–185. https://doi.org/10.1177/030089160409000204.

Pesatori, A.C., Consonni, D., Rubagotti, M., Grillo, P., Bertazzi, P.A., 2009. Cancer incidence in the population exposed to dioxin after the "Seveso accident": twenty years of follow-up. Environ. Health 8, 39. https://doi.org/10.1186/1476-069X-8-39.

Praud, D., Amadou, A., Coudon, T., Duboeuf, M., Mercoeur, B., Faure, E., Grassot, L., Danjou, A.Mn, Salizzoni, P., Couvidat, F., Dossus, L., Severi, G., Mancini, F.R., Fervers, B., 2025. Association between chronic long-term exposure to airborne dioxins and breast cancer. Int. J. Hyg. Environ. Health 263, 114489. https://doi.org/10.1016/j.ijheh.2024.114489.

Pronk, A., Nuckols, J.R., De Roos, A.J., Airola, M., Colt, J.S., Cerhan, J.R., Morton, L., Cozen, W., Severson, R., Blair, A., Cleverly, D., Ward, M.H., 2013. Residential proximity to industrial combustion facilities and risk of non-Hodgkin lymphoma: a case–control study. Environ. Health 12, 20. https://doi.org/10.1186/1476-069X-12-20.

R Core Team (2024). _R: A Language and Environment for Statistical Computing_. R Foundation for Statistical Computing, Vienna, Austria.<https://www.R-project.org/>.

Raffetti, E., Treccani, M., Donato, F., 2019. Cement plant emissions and health effects in the general population: a systematic review. Chemosphere 218, 211–222. https://doi.org/10.1016/j.chemosphere.2018.11.088.

Ranzi, A., Fano, V., Erspamer, L., Lauriola, P., Perucci, C.A., Forastiere, F., 2011. Mortality and morbidity among people living close to incinerators: a cohort study based on dispersion modeling for exposure assessment. Environ. Health 10, 22. https://doi.org/10.1186/1476-069X-10-22.

Reeve, N.F., Fanshawe, T.R., Keegan, T.J., Stewart, A.G., Diggle, P.J., 2013. Spatial analysis of health effects of large industrial incinerators in England, 1998–2008: a study using matched case–control areas. BMJ Open. 3, e001847. https://doi.org/10.1136/bmjopen-2012-001847.

Rhee, J., Medgyesi, D.N., Fisher, J.A., White, A.J., Sampson, J.N., Sandler, D.P., Ward, M. H., Jones, R.R., 2023. Residential proximity to dioxin emissions and risk of breast cancer in the sister study cohort. Environ. Res. 222, 115297. https://doi.org/10.1016/j.envres.2023.115297.

Rogers, K., Jaspers, I., 2025. ToxPoint: Waste incineration management of plastic materials—an issue of increasing global public health importance. Toxicol. Sci. 206, 230–232. https://doi.org/10.1093/toxsci/kfae111.

Romanelli, A.M., Bianchi, F., Curzio, O., Minichilli, F., 2019. Mortality and Morbidity in a Population Exposed to Emission from a Municipal Waste Incinerator. A Retrospective Cohort Study. IJERPH 16, 2863. https://doi.org/10.3390/ijerph16162863.

Roumeliotis, S., Abd ElHafeez, S., Jager, K.J., Dekker, F.W., Stel, V.S., Pitino, A., Zoccali, C., Tripepi, G., 2021. Be careful with ecological associations. Nephrology 26, 501–505. https://doi.org/10.1111/nep.13861.

Salerno, C., Marciani, P., Barasolo, E., 2015. Exploration study on mortality trends in the territory surrounding an incineration plant of urban solid waste in the municipality of Vercelli (Piedmont, Italy) 1988-2009. Annali Di Igiene Medicina Preventiva e Di Comunitá 633–645. https://doi.org/10.7416/ai.2015.2055.

Sharma, Raman, Sharma, M., Sharma, Ratika, Sharma, V., 2013. The impact of incinerators on human health and environment. Rev. Environ. Health 28, 67–72. https://doi.org/10.1515/reveh-2012-0035.

Song, F., Parekh, S., Hooper, L., Loke, Y., Ryder, J., Sutton, A., Hing, C., Kwok, C., Pang, C., Harvey, I., 2010. Dissemination and publication of research findings: an updated review of related biases. Health Technol. Assess. 14. https://doi.org/10.3310/hta14080.

Steenland, K., Bertazzi, P., Baccarelli, A., Kogevinas, M., 2004. Dioxin Revisited: Developments Since the 1997 IARC Classification of Dioxin as a Human Carcinogen. Environ. Health Perspect. 112, 1265–1268. https://doi.org/10.1289/ehp.7219.

Tait, P.W., Brew, J., Che, A., Costanzo, A., Danyluk, A., Davis, M., Khalaf, A., McMahon, K., Watson, A., Rowcliff, K., Bowles, D., 2020. The health impacts of waste incineration: a systematic review. Aust. N. Z. J. Public. Health 44, 40–48. https://doi.org/10.1111/1753-6405.12939.

UN Environment Programme, 2022. Solid waste management [WWW Document]. URL ⟨https://www.unep.org/explore-topics/resource-efficiency/what-we-do/cities/solid-waste-management⟩ (accessed 10.6.25).

Valberg, P.A., Drivas, P.J., McCarthy, S., Watson, A.Y., 1996. Evaluating the health impacts of incinerator emissions (Municipal Waste Incineration). J. Hazard. Mater. 47, 205–227. https://doi.org/10.1016/0304-3894(96)82225-4.

Valizadeh, B., Abdoli, M.A., Dobaradaran, S., Mahmoudkhani, R., Asl, Y.A., 2024. Risk control of heavy metal in waste incinerator ash by available solidification scenarios in cement production based on waste flow analysis. Sci. Rep. 14, 6252. https://doi.org/10.1038/s41598-024-56551-y.

Viel, J.-F., Arveux, P., Baverel, J., Cahn, J.-Y., 2000. Soft-Tissue Sarcoma and Non-Hodgkin's Lymphoma Clusters around a Municipal Solid Waste Incinerator with High Dioxin Emission Levels. Am. J. Epidemiol. 152, 13–19. https://doi.org/10.1093/aje/152.1.13.

Viel, J.-F., Daniau, C., Goria, S., Fabre, P., De Crouy-Chanel, P., Sauleau, E.-A., Empereur-Bissonnet, P., 2008b. Risk for non Hodgkin's lymphoma in the vicinity of French municipal solid waste incinerators. Environ. Health 7, 51. https://doi.org/10.1186/1476-069X-7-51.

Viel, J.-F., Clément, M.-C., Hägi, M., Grandjean, S., Challier, B., Danzon, A., 2008a. Dioxin emissions from a municipal solid waste incinerator and risk of invasive breast cancer: a population-based case-control study with GIS-derived exposure. Int. J. Health Geogr. 7, 4. https://doi.org/10.1186/1476-072X-7-4.

Vinti, G., Bauza, V., Clasen, T., Medlicott, K., Tudor, T., Zurbrügg, C., Vaccari, M., 2021. Municipal solid waste management and adverse health outcomes: a systematic review. Int. J. Environ. Res. Public. Health 18, 4331. https://doi.org/10.3390/ijerph18084331.

VoPham, T., Bertrand, K.A., Jones, R.R., Deziel, N.C., DuPré, N.C., James, P., Liu, Y., Vieira, V.M., Tamimi, R.M., Hart, J.E., Ward, M.H., Laden, F., 2020. Dioxin exposure and breast cancer risk in a prospective cohort study. Environ. Res. 186, 109516. https://doi.org/10.1016/j.envres.2020.109516.

VoPham, T., Bertrand, K.A., Fisher, J.A., Ward, M.H., Laden, F., Jones, R.R., 2022. Emissions of dioxins and dioxin-like compounds and incidence of hepatocellular carcinoma in the United States. Environ. Res. 204, 112386. https://doi.org/10.1016/j.envres.2021.112386.

Yao, X., Steven Xu, X., Yang, Y., Zhu, Zhi, Zhu, Zhao, Tao, F., Yuan, M., 2021. Stratification of population in NHANES 2009–2014 based on exposure pattern of lead, cadmium, mercury, and arsenic and their association with cardiovascular, renal and respiratory outcomes. Environ. Int. 149, 106410. https://doi.org/10.1016/j.envint.2021.106410.