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Cancer Risk Associated with Residential Proximity to Municipal Waste Incinerators: A Review of Epidemiological and Exposure Assessment Studies

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Posted Date: 18 February 2025

doi: 10.20944/preprints202502.1320.v1

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 doi:10.20944/preprints202502.1320.v1

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Cancer Risk Associated with Residential Proximity to Municipal Waste Incinerators: A Review of Epidemiological and Exposure Assessment Studies

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Abstract: Municipal Solid Waste Incinerators (MSWIs) are facilities designed to burn municipal solid waste to reduce its volume and mass and generate energy. A significant concern related to MSWIs is the emission of toxic and carcinogenic pollutants, including polychlorinated dibenzo-p-dioxins and furans (PCDD/Fs), heavy metals, and particulate matter. This review synthesizes global epidemiological and exposure assessment studies investigating cancer risks associated with residential proximity to MSWIs. Findings reveal a complex relationship: older incinerators with high emissions correlate with elevated risks of non-Hodgkin lymphoma (NHL), soft-tissue sarcoma (STS), and liver cancer in some studies, particularly in Europe. However, results remain inconsistent due to methodological limitations such as exposure misclassification, latency periods, and confounding factors like socioeconomic status. Modern facilities equipped with advanced pollution control technologies demonstrate reduced risks, often within regulatory thresholds. Key challenges include accurately quantifying historical exposures and disentangling MSWI-specific risks from other environmental or lifestyle factors. While advancements in dispersion modeling and biomonitoring have improved risk assessments, geographical and temporal variations in findings underscore the need for continued research. The review concludes that while historical evidence suggests potential cancer risks near older MSWIs, stricter emissions regulations and technological improvements have mitigated health impacts, although vigilance through long-term monitoring remains essential to safeguard public health.

Keywords: municipal solid waste incinerators (MSWIs); cancer risks; epidemiological studies; exposure assessment; environmental health

1. Introduction

The incineration of municipal solid waste (MSW) stands as a common and efficient strategy for managing waste across numerous nations. While municipal solid waste incinerators (MSWIs) effectively diminish waste volume and, in some instances, generate power, they also release pollutants into the surrounding environment [1,2]. These emissions encompass highly hazardous and persistent organic pollutants, such as polychlorinated dibenzo-p-dioxins and dibenzofurans (PCDD/Fs), alongside arsenic, heavy metals, particulate matter (PM) capable of penetrating deeply into the lungs, polycyclic aromatic hydrocarbons (PAHs) resulting from incomplete combustion, and various gaseous pollutants (SO2, NOx, CO) [3–9]. The International Agency for Research on Cancer (IARC) has classified several pollutants emitted by MSWIs as Group 1 carcinogens, with 2,3,7,8-TCDD being a notable example [10]. In addition, elements like arsenic are implicated in lung, bladder, and skin cancers through mechanisms involving oxidative stress and DNA hypomethylation, while cadmium has been linked to breast and prostate cancers, and chromium (VI) can induce DNA strand breaks. Long-term exposure to these toxicants, whether through inhalation, contaminated soil, or food, may act synergistically to elevate cancer risks, especially among vulnerable populations.

 doi:10.20944/preprints202502.1320.v1

The potential health effects of PCDD/Fs, arsenic, and other toxic elements have prompted extensive research, including cancer risks in populations living near MSWIs [11–14]. The present review analyzes scientific literature, focusing on epidemiological studies and exposure assessments, investigating residential proximity to MSWIs and cancer risks. The objectives of the review are to: a) critically evaluate epidemiological evidence linking MSWI proximity to cancer, b) summarize exposure assessment studies on cancer and toxic emissions of MSWIs, and c) discuss current policies and research priorities.

2. Methodology

Literature Search

A search of PubMed, Scopus, and Web of Science was conducted using the following keywords: "municipal solid waste incinerators," "MSWI," "cancer risks," "PCDD/Fs," "dioxins," "heavy metals," "environmental exposure," and combinations thereof. Inclusion criteria were peer-reviewed human studies. The search period ran until January 31, 2025. It must be remembered that the emissions of dioxins by MSWIs were reported for the first time by Olie et al. [3]. For data extraction and synthesis, studies were categorized by geographic region. Risk estimates and exposure metrics (distance, biomonitoring) were compared.

3. Summary of European Studies on Cancer and Waste Incinerators

Great Britain

Elliott et al. [15–17] investigated the incidence of cancer near various incinerators in the UK, focusing on different types of cancer and geographical areas over several years. In a first study, Elliott et al. [15] examined the incidence of larynx and lung cancers near the Charnock Richard incinerator and nine other similar sites. Using cancer registration data from 1974-1984 (England and Wales) and 1975-1987 (Scotland), the researchers calculated standardized observed/expected (O/E) ratios within 3 km and 3-10 km of each site, adjusting for socioeconomic factors. The results showed no significant differences in O/E ratios for either cancer type or lag period, and there was no evidence of decreasing risk with distance from the sites. This led to the conclusion that the reported cancer cluster near Charnock Richard was unlikely due to the incinerator. Based on this, in a subsequent study, Elliott et al. [16] expanded the survey to 72 MSWIs, analyzing cancer incidence data from 1974-1986 (England and Wales) and 1975-1987 (Scotland). The study compared observed cases with expected numbers, adjusted for a deprivation index, and assessed risk up to 7.5 km from the incinerators. The findings indicated a significant decline in risk with distance for all cancers combined, as well as for stomach, colorectal, liver, and lung cancers. However, the excess risk near incinerators was attributed to residual confounding and misdiagnosis, particularly for liver cancer. This highlighted the need for further investigations to determine the true increase in primary liver cancer. Thus, Elliott et al. [17] carried out another study focused specifically on confirming the excess risk of liver cancer near municipal incinerators. Reviewing 119 out of 235 cases, the researchers confirmed primary liver cancer in 66 cases. Revised estimates of excess cases per year within 1 km ranged from 0.53 to 0.78 per 100,000. The study emphasized the necessity of further histological review to confirm the increase in primary liver cancer. The studies by Elliott et al. [15–17] underscored the importance of thorough analysis and continued investigation to understand the potential health impacts of incinerators, particularly concerning cancer incidence. Also in the UK, Knox [18] reported associations between the incidence of childhood cancers and proximity to industrial sites, including incinerators, further supporting the hypothesis of a link between industrial emissions and cancer risk, particularly in vulnerable populations.

Italy

 doi:10.20944/preprints202502.1320.v1

Several epidemiological studies have explored the potential health impacts of incineration plants, primarily focusing on cancer incidence and mortality. Early research included a retrospective mortality study by Rapiti et al. [19] of 532 male workers at two municipal waste plants followed from 1965 to 1992. This study found overall mortality lower than expected but identified a significantly increased risk for gastric cancer, particularly with more than 10 years since first exposure, suggesting a possible link between occupational exposure to organic dust and bacterial endotoxins in waste management. In contrast, mortality from lung cancer was reduced in this worker cohort. Parodi et al. [20] conducted an ecological study assessing lung cancer mortality in areas of La Spezia exposed to pollution from a coal-fired power station and a waste incinerator. While no significant excess risk was found in males after excluding rural and semi-rural zones from the analyses, females exhibited a significant increased risk in both exposed areas, even after controlling for deprivation factors. The authors suggested that occupational exposures and smoking habits could explain the lack of excess risk in men but noted that the ecological design limited causal inference. On the other hand, Biggeri and Catalan [21] examined mortality for lymphohematopoietic tumors and soft-tissue sarcoma (STS) in residents near an urban waste incinerator in Campi Bisenzio. The study identified a localized cluster of non-Hodgkin lymphoma (NHL) deaths in males during 1986-1992, a period when the urban waste incinerator was operating. The incinerator's subsequent closure in 1986 followed evidence of dioxin soil contamination. Zambon et al. [22] further explored sarcoma risk in relation to environmental pollution from PCDD/Fs emitted by waste incinerators and industrial sources in the Province of Venice. A case-control study design, incorporating atmospheric dispersion modeling (ISCLT3) to estimate dioxin exposure levels, found a 3.3 times higher risk of developing sarcoma among subjects with the longest exposure period and highest exposure level. A significant excess risk was also observed in women and for cancers of connective and other soft tissue. Cangialosi et al. [23] performed a health risk assessment of long-term emissions from a MSWI in Taranto. The study estimated ground-level air concentrations and soil deposition of carcinogenic (PCDD/Fs and Cd) and non-carcinogenic pollutants using atmospheric dispersion modeling. Their results indicated that individual risks were well below maximum acceptable levels, with a very small incremental cancer risk compared to background levels, suggesting that the MSWI emissions did not pose a significant health risk to the surrounding population. More recently, Chellini et al. [24] evaluated the health impact of emissions from two waste incinerators in Pietrasanta, Tuscany. They observed a higher case distribution in higher pollution levels, with significant increases for liver cancer, larynx cancer, lung cancer, NHL, and leukemia. Risks estimated for STS, although non-significant, were consistent with those obtained in previous studies undertaken in areas characterized by PCDD/F pollution. The study suggested a potential health impact from the old incinerator's emissions but acknowledged the possible role of other risk factors like occupations and lifestyles. Adding to the body of evidence, Federico et al. [25] conducted a retrospective ecological study to assess cancer incidence during the period 1991-2005 in proximity of a MSWI in Modena. They identified three bands of increasing distance from the MSWI, up to a radius of 5 km, using residence as a surrogate marker of exposure. Age-standardized incidence ratios (ASR) and standardized incidence ratios (SIR) were estimated for all cancers and selected sites. Variations in cancer incidence were investigated using space and space-time scan statistics, with a deprivation index considered as a potential confounding factor. The space-time clustering test identified three significant clusters, but their shapes were not associable to the MSWI exposure. The purely spatial analysis not showed statistically significant clusters. The SIR computed for all cancers and selected sites did not show any excess of risk in the area closest to the facility. Higher SIR for leukemia was found in the second band from MWI (2-3.5 km) for females and for both sexes, but not a spatial trend was observed, thus excluding a possible link with the MSWI. The results suggest that there is no detectable increase of cancer risk for people living in proximity to the Modena MSWI. Ranzi et al. [26] investigated the health effects of emissions from two incinerators in Forli, using a longitudinal cohort of 31,347 residents. No overall increased risk of mortality or morbidity was found compared to the regional population. However, internal analysis based on exposure levels showed an association between incinerator emissions and cancer mortality in

 doi:10.20944/preprints202502.1320.v1

women, particularly for all cancer sites, stomach, colon, liver, and breast cancer. No clear trend was observed for cancer incidence, and no significant association was found for hospitalizations due to major diseases. The study's interpretation is limited by its pilot nature. In turn, Salerno et al. [27,28] performed a geographic analysis study on mortality in the town of Vercelli, addressing concerns from the population and local administrators. The study focused on the presence of various sources of environmental and industrial pressure, including an old-generation incinerator for solid urban waste, an industrial site for chemicals production, and intense agricultural activity of rice production. The study analyzed census and ISTAT death cards, using both epidemiological approaches and SMR standardized spatial analysis using Bayesian models. Overall, both approaches highlighted major risks for the area south of the capital for major cancers such as colorectal and lung and increases worthy of investigation for the young-adult age groups in both genders. Minichilli et al. [29] evaluated whether exposure to an urban waste incinerator plant operating in Arezzo (Tuscany Region) since the 2000 is associated with mortality and morbidity. A population-based cohort study of inhabitants living close to the incinerator in the period 2001-2010 was conducted. The individual exposure histories to the incinerator and other sources in the area were estimated using a dispersion model producing PM10 concentration maps for each source (ADMS-URBAN model). Hazard Ratios (HR) adjusted for the other environmental exposures, age and socioeconomic status were estimated. Morbidity analysis showed an increased risk for cardiovascular diseases and a trend of HRs for urinary diseases. Mortality analysis showed a trend of HRs for general mortality in males, for cardiovascular diseases in males, for respiratory diseases in females, and an excess of acute respiratory diseases in females with the highest exposure. The increased risks for cardiovascular and respiratory diseases reinforce the limited epidemiological evidence on health effects of incinerators. Romanelli et al. [30] evaluated the health effects of exposure to the MSWI in Pisa, Italy, through a population-based cohort design. The individual exposure pattern in the area was estimated through CALPUFF dispersion models of NOx, used as pollution proxies of the MSWI and the relevant industrial plant, and through land-use regression for NOx due to traffic pollution. Using Cox regression analysis, HR were estimated adjusting for exposure to other sources of pollution, age, and socioeconomic deprivation. Analysis on males showed increased trends of mortality due to natural causes, the tumor of the lymphohematopoietic system cardiovascular diseases, in females, increased trends for acute respiratory diseases. Morbidity analysis showed a HRt for lymphohematopoietic system tumor in males. Some of the excesses agree with previous evidence on the health effects of MSWIs. In turn, Di Maria et al. [31] assessed, by a life cycle assessment (LCA) approach, the impact of a MSWI on the environment and on human health. The LCA performed for the Italian MSWI detected avoided impacts of about -0.11 kgPM2,5eq/ton of MSW and of about -2.5 × 10-3 kgSbeq/ton MSW for particulate matters and resource depletion, respectively. Positive impacts of about 900 kgCO2eq/ton MSW and about 15,000 CTUe/ton MSW were detected for global warming and freshwater ecotoxicity indicators, respectively. Avoided impacts of about -1 × 10-6 CTUh/ton MSW and of about -2 × 10-4 DALY/ton MSW were also detected for human toxicity cancer and human health indicators, respectively. A general coherence between LCA and epidemiologic approaches was detected. Recently, the same research group [32] integrated LCA with a review of epidemiological and oxidative potential studies to evaluate current evidence on the impact of airborne emissions from MSW incineration on human health. Their LCA results suggested that MSWI can potentially mitigate negative impacts on human health, estimating an avoidance of approximately - 2 × 10-4 DALY/ton, coupled with reductions in particulate matter (PM) emissions and resource depletion, at about - 2.5 × 10-3 kg Sbeq/ton and approximately - 0.11 kg PM2.5 eq/ton, respectively. The findings of epidemiological studies on populations exposed to MSWI were inconsistent. However, there appears to be a greater degree of consensus regarding the incidence of larynx and lung cancer. Furthermore, the oxidative potential of PM demonstrated a strong Pearson correlation (> 0.8) with the presence of Cr(VI), Cu, and Zn. Piccinelli et al. [33] assessed the health effects on the resident population around the MSWI in Valmadrera (Lombardy Region) in relation to the exposure level to the pollutants produced by the plant. A historical cohort study, based on the resident population from 2003 to 2016

 doi:10.20944/preprints202502.1320.v1

in the study area was used. With a dispersion model, based on PM10 emitted by the plant, three areas of exposure (high, medium, low) were defined. There were no significant excesses of risk for almost all the outcomes investigated. Excessive mortality and hospitalization were found for liver/biliary cancers. In the municipality where the plant is located, an excess prevalence of hepatitis C was found. The results suggested the absence of a relationship between residence in areas with different levels of pollutants emitted by the plant and the onset of almost all diseases. The body of Italian research on waste incinerators and cancer reveals a complex and evolving picture. Early studies raised concerns about increased risks of specific cancers, particularly STS and NHL, linked to exposure to PCDD/Fs near incinerators. However, more recent studies have shown no significant association or even potential risk reductions, possibly due to advancements in incinerator technology and stricter environmental regulations. The influence of confounding factors and the ecological nature of some investigations highlight the need for further research with individual exposure assessments and comprehensive consideration of other variables to fully understand the long-term health effects of waste incineration.

France

French epidemiological research has extensively examined the potential health effects associated with MSWIs, with a particular emphasis on PCDD/Fs. These studies have employed diverse approaches, including spatial analyses, case-control designs, ecological studies, and biomarker measurements to evaluate the impacts on cancer incidence, especially STS and NHL. Initial investigations focused on identifying spatial clusters of cancer around MSWIs with high PCDD/F emissions. Viel et al. [34] examined the area surrounding a MSWI (Besançon) with high emission levels (16.3 ng I-TEQ/m3). Spatial scan statistics identified overlapping clusters of STS and NHL near the incinerator between 1980 and 1995, demonstrating elevated standardized incidence ratios of 1.44 and 1.27, respectively. The research determined that Hodgkin's disease, serving as a control, did not exhibit any specific spatial distribution. While these findings hinted at a potential link between MWSI emissions and cancer incidence, the authors called for further case-control studies with PCDD/F measurements in biological tissues. Thus, Floret et al. [35] carried out a population-based case-control study in the same area to investigate the association between NHL and PCDD/F exposure. Comparing 222 incident cases of NHL (diagnosed between 1980 and 1995) with matched controls, the study used modeled dioxin concentrations to assign exposure levels based on residential histories. Individuals at the highest PCDD/F concentrations area faced a 2.3 times higher risk of developing NHL compared to those in the lowest concentration area. The results suggested that environmental PCDD/Fs could increase the risk of NHL among those living near MSWIs, despite incinerators not being the primary source of PCDD/F exposure in comparison to other background contributors. However, a microspatial study by the same group [36], focusing on the association between PCDD/Fs emitted by the same MSWI (Besançon) and STS risk, found no significant increase. Despite identifying 37 STS cases between 1980 and 1995, corresponding to a standardized incidence of 2.44 per 100,000 inhabitants, living in more exposed zones did not significantly increase the risk of developing STS. Before definitive conclusions concerning the link between PCDD/F exposure from MSWIs and STS could be drawn, a nationwide investigation based on other registries was proposed. Further source characterization work was conducted by Floret et al. [37], who examined PCDD/F soil contamination patterns surrounding the MSWI. By analyzing congener profiles in 75 soil samples, they determined that the area under influence of the MSWI was not subject to other point sources of PCDD/Fs. Recent updates to the combustion chambers with more modern pollution control measures were also expected to reduce PCDD/F concentrations in the soil. Viel et al. [38] shifted focus to investigate the association between PCDD/Fs emitted from the same MSWI and invasive breast cancer risk among women. Through a case-control study comparing 434 incident cases with 2170 controls and leveraging a validated dispersion model for PCDD/F exposure assessment, the authors identified no increased or decreased risk among women younger than 60. Interestingly, women over 60 in the highest exposure zone were significantly less likely (0.31 times) to develop invasive breast cancer, leading to the cautiously proposed hypothesis of potential dioxin anti-estrogenic activity

 doi:10.20944/preprints202502.1320.v1

affecting late-onset breast cancer, or the possible presence of residual confounding. Recognizing the growing body of evidence linking NHL to MSWIs with high PCDD/F emission levels, Viel et al. [39] conducted a broader population-based study across four French administrative departments. This large-scale analysis considered 3974 NHL cases diagnosed between 1990 and 1999 and utilized Atmospheric Dispersion Model System software to estimate immissions from 13 MSWIs operating in the study areas. The results suggested a significant relationship at the block group level between the risk for NHL and PCDD/F exposure, with a relative risk of 1.120 for individuals in highly exposed areas. Subgroup analyses indicated a significant RR (1.178) for females only. While that study reinforced the association between NHL incidence and exposure to PCDD/Fs from MSWIs, the researchers noted that the findings might not be applicable to modern incinerators due to their lower pollutant emissions. Goria et al. [40] also conducted an ecological study in the same region. The study emphasized the importance of advanced tools and statistical techniques to better assess weak associations between the risk of cancer and past environmental exposures. Dispersion modeling assessed exposure to 16 incinerators, and GIS defined an exposure index. Potential confounding factors were considered and generalized additive models and Bayesian hierarchical models estimated associations between cancer risk and incinerator exposure, accounting for confounders. That study highlighted the importance of using advanced methods to better assess dose-response relationships with disease risk because in most epidemiological studies distance is still used as a proxy for exposure which can lead to significant exposure misclassification. Viel et al. [41] investigated organochlorines and the risk of NHL among neighbors of the Besançon MSWI, using serum concentrations to assess exposure. Serum analysis of 34 newly diagnosed NHL cases and 34 controls revealed associations between NHL risk and various pesticides, as well as PCDD/Fs and dioxin-like PCBs. That research supported a link between serum cumulative WHO-TEQ concentrations and the risk of NHL among those residing near a MSWI. More recently, Mariné Barjoan et al. [42] investigated cancer incidence near a MSWI in Nice, comparing it to the broader Alpes-Maritimes department from 2005-2014. Researchers geolocated over 80,000 cancer cases and categorized them by exposure based on modeled dioxin deposition. In the first period (2005-2009), exposed women showed higher rates of certain blood cancers, while exposed men had higher rates of STS, myeloma, and lung cancer. Between 2010 and 2014, only men in the exposed area continued to show higher rates of myeloma and lung cancer. The authors suggested that stricter EU emission regulations might explain the decrease in some cancers with longer latency periods. In summary, the French studies provide a detailed, nuanced view of the potential health effects of MSWIs, particularly those with high historical emissions of PCDD/Fs. While some studies identified associations between living near MSWIs and increased risks of NHL and, in some cases, STS, others have found no such associations, or even inverse relationships. The use of advanced modeling and statistical methods has enriched the evidence base yet challenges in addressing confounding factors and the evolution of incinerator technologies necessitate careful interpretation of findings. These studies showed a progression of understanding as technology improves and analytical methods become more precise.

Spain

Meneses et al. [43] assessed the added lifetime cancer risk from PCDD/Fs for individuals residing near a MSWI in Montcada, Catalonia. The study also aimed to quantify potential decreases in health risks following the facility's compliance with EU regulations concerning pollutant emissions, especially PCDD/Fs. To determine PCDD/F concentrations in environmental media, analytical measurements and modeling were conducted using a simplified multimedia model encompassing air, soil, and vegetation. By comparing predicted concentrations with measured levels in soils and vegetation, the study evaluated the influence of MSWI emissions. The estimated cancer risks attributed to PCDD/F emissions from the plant were 1.07E-07 before and 3.08E-09 after the implementation of a clean air system, respectively. However, other sources of PCDD/F emissions in the region contributed cancer risks of 5.54E-06 and 1.86E-06. Considering total PCDD/F cancer risks, including those from dietary intake, for the population living near the MSWI, the values were 1.3E-04 and 4.25E-05, reflecting a 67.6% reduction [43]. On the other hand, a surveillance program was

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initiated in 1996 to comprehensively assess the impact of a MSWI in Tarragona, Catalonia. PCDD/Fs concentrations were periodically measured in soil and vegetation samples collected around the incinerator. Air PCDD/F levels were also monitored using active and passive sampling devices. The survey conducted in 2009-2010 showed mean PCDD/F levels in vegetation, soil, and air of 0.06 ng I-TEQ kg(-1), 0.58 ng I-TEQ kg(-1), and 10.5 fg WHO-TEQ m(-3), respectively. Human exposure to PCDD/Fs was evaluated under various scenarios and associated non-carcinogenic and carcinogenic risks were assessed. In all cases, the hazard quotient was < 1, while cancer risks were under 10(-6), below the maximum recommended guidelines [44]. In 2014, a study screened the concentrations of PCDD/Fs and various trace elements in air and soil samples collected in an urban area of Sant Adrià de Besòs, Barcelona, near an Integrated Waste Management Facility (IWMF) [45]. The facility included a mechanical-biological treatment plant (MBT) and an older MSWI. Human health risks for the local population were also assessed, revealing high cancer risks estimated for the area (2.5×10-6). A follow-up survey was carried out in March 2017 aimed to determine if authorities had taken necessary measures to reduce environmental PCDD/F concentrations and human health risks to acceptable levels. Although soil PCDD/F concentrations were lower (mean value: 1.66 vs. 3.6 ng WHO-TEQ/kg in 2014), they remained notably higher than those near other MSWIs in Catalonia. Air PCDD/F levels were even higher than in 2014 (mean value: 0.044 vs. 0.026 pg WHO-TEQ/m3), being the highest detected in similar zones of Catalonia. Consequently, the current cancer risk due to PCDD/F exposure for residents near the IWMF was 2.3×10-6, still exceeding the 10-6 threshold [46]. Recently, Domingo et al. [47] published a review aimed at examining health effects, including cancer incidence and mortality, for individuals residing near hazardous waste incinerators (HWIs) and MSWIs. The review raised questions about the safety of the 0.1 ng TEQ/Nm3 limit for PCDD/Fs, seeking evidence supporting this standard. Risk assessment studies have typically focused on heavy metals and PCDD/Fs, potentially neglecting other chemicals that are not routinely analyzed or even currently unknown. Furthermore, the review questioned the consideration of potential interactions among chemicals in estimating carcinogenic and non-carcinogenic risks for populations near incinerators, emphasizing the need for complete epidemiological studies. Domingo et al. [48] recently reported the results of a 20-year follow-up study focused on investigating PCDD/F emissions from the MSWI in Sant Adrià de Besòs. Samples of ambient air, soils, and herbage were periodically collected near the facility, and PCDD/F content was analyzed. The latest (2017) survey indicated mean soil levels of 3.60 ng WHO-TEQ/kg (range: 0.40-10.6), considerably higher than mean PCDD/F concentrations in soil samples near other MSWIs in Catalonia. Air PCDD/F concentrations were also higher than in a previous (2014) survey, increasing from 0.026 to 0.044 pg WHO-TEQ/m3. Ultimately, PCDD/F exposure was associated with a cancer risk (2.5 × 10-6) for the population living in the surrounding area. The results suggests that the MSWI of Sant Adrià de Besòs might have negatively impacted the environment and public health due to possible inappropriate management over the years.

Table 1. Summary of European Studies on Cancer and Waste Incinerators.

Country	Kind of Study	Population Studied	Highlights	Reference
UK	Cohort	Residents near 72 MSWIs (1974–1987)	Significant decline in cancer risk with distance for stomach, colorectal, liver, and lung cancers; excess risk attributed to confounding.	Elliott et al. [15–17]
Italy	Retrospective Mortality	532 male workers at two MSWIs (1965–1992)	Increased risk of gastric cancer after 10+ years of exposure; reduced lung cancer mortality.	Rapiti et al. [19]

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Italy	Ecological	Residents near Modena MSWI (1991–2005)	No significant cancer clusters or excess risk near the MSWI.	Federico et al. [25]
Italy	Cohort	Residents near Arezzo MSWI (2001–2010)	Increased cardiovascular and respiratory disease mortality/morbidity; no significant cancer risks.	Minichilli et al. [29]
France	Spatial Analysis	Residents near Besançon MSWI (1980–1995)	Clusters of STS and NHL near the incinerator (SIR = 1.44 and 1.27).	Viel et al. [34]
France	Case-Control	222 NHL cases vs. controls near Besançon MSWI	2.3x higher NHL risk in highest PCDD/F exposure areas.	Floret et al. [35]
France	Cohort	Women near Besançon MSWI	No increased breast cancer risk except reduced risk in women >60 (OR = 0.31).	Viel et al. [38]
Spain	Risk Assessment	Residents near Montcada MSWI	Cancer risk reduced by 67.6% after EU emission controls; total risk remained below thresholds.	Meneses et al. [43]
Spain	Environmental Monitoring	Residents near Sant Adrià de Besòs MSWI (2014–2017)	PCDD/F levels and cancer risks (2.3×10^{-6}) exceeded thresholds despite improvements.	Domingo et al. [46]

4. Summary of American Studies on Cancer and Waste Incinerators

United States

Nessel et al. [49] performed a cancer risk assessment of PCDD/F emissions from a MSWI to evaluate the relative contribution of various exposure routes. Life-time cancer risk from the emitted PCDD/Fs was assessed for each scenario and was estimated as 1.8 x 10(-7) (common case), 2.5 x 10(-6) (highly exposed case), and 6.7 x 10(-6) (worst case). The relatively low magnitude of these risks suggests that the PCDD/F emissions from that MSWI should not be considered a significant public health concern. Hallenbeck et al. [50] assessed cancer risks from metal emissions of MSWIs in Chicago, focusing on carcinogenic metals such as arsenic, cadmium, chromium, beryllium, and nickel. The study identified arsenic and chromium (VI) as the most toxic, with cumulative cancer risks exceeding the EPA's 1 in 1 million threshold, especially for populations near incinerators. Pronk et al. [51] conducted a population-based case-control study of NHL in four National Cancer Institute-Surveillance Epidemiology and End Results centers. The study evaluated residential proximity to dioxin-emitting facilities and found no overall association between proximity to any dioxin-emitting facility and NHL risk. However, there was an elevated risk for residence near cement kilns and a reduced risk for residence near MSWIs. More recently, VoPham et al. [52] prospectively examined the association between ambient PCDD/F exposure and invasive breast cancer risk in the Nurses' Health Study II (NHSII). The study found that women residing within 10 km of any MSWI had an increased breast cancer risk compared to those who did not, with stronger associations noted for women who lived within 5 km. Positive associations were also observed for longer duration of residence and higher PCDD/F emissions from MSWIs. Rhee et al. [53] investigated the link between residential exposure to industrial emissions of PCDD/Fs and breast cancer risk in a large US cohort. It followed 35,908 participants, identifying 2,670 breast cancer cases. Higher exposure to airborne PCDD/Fs within 3 km increased breast cancer risk, with the highest quartile showing an 18% higher

 doi:10.20944/preprints202502.1320.v1

risk. The association was stronger for emissions from MSWIs. Ever smokers had a significantly higher risk, and a potential link with ER-negative tumors was suggested. Recently, Fisher et al. [54] evaluated the associations between residential proximity to PCDD/F-emitting facilities and NHL in the NIH-AARP Diet and Health Study. The study found that participants with an AEI-W ≥ 95th percentile had elevated risk of NHL compared to those unexposed at 3, 5, and 10 km. A positive association was observed at 5 km with follicular lymphoma and a suggestive association was noted for diffuse large B-cell lymphoma. NHL risk was also associated with high emissions from coal-fired power plants within 10 km. In another vein, Moy et al. [55] performed health risk assessments for landfill disposal versus WTE treatment options for the management of New York City's MSW. The overall results indicated that the individual cancer risks for both options would be considered generally acceptable, although the risk from landfilling is approximately 5 times greater than from WTE treatment.

Canada

Ollson et al. [56] reported the results of a comprehensive human health risk assessment for an energy-from-waste thermal treatment facility in Durham and York, Ontario. The assessment indicated that facility-related emissions are unlikely to cause adverse health risks (including cancer) to residents, farmers, or other receptors for the initial operating design capacity of the facility (140,000 tons per year).

5. Summary of Asian Studies on Cancer and Waste Incinerators

Japan

Yoshida et al. [57] evaluated the human health risk of PCDD/Fs for four Japanese receptor groups: the general population, residents living near a MSWI, heavy fish consumers, and their infants and fetuses. Although the estimated risk of cancer was not exceptionally high in the three adult receptor groups, the margin of exposure (MOE) values for neurobehavioral effects on infants and fetuses suggested that PCDD/Fs might cause a considerable risk to those of residents living near a MSWI, and heavy fish consumers.

Taiwan

Ma et al. [58] assessed site-specific carcinogenic risks of incinerator-emitted dioxins and risk transfers among the areas covered by nine municipal waste incinerators. The study found that dioxins' carcinogenic risks ranged from 1.4 x 10(-8) to 7.1 x 10(-5) for the nine incinerators under the exposure scenario of sufficient food production (SFP), and ranged from 8.7 x 10(-8) to 1.1 X 10(-6) under the exposure scenario of insufficient food production (IFP). Food ingestion was the main exposure pathway, accounting for 64-99% of total dioxin risks. In turn, Shih et al. [59] characterized and compared PCDD/Fs in the surrounding environment (outdoor) and workplace air of two MSWIs in northern Taiwan. It was found that the total PCDD/F and total PCDD/F WHO-TEQ concentrations in the workplace air were 5-13 and 5-15 times higher than those in the outdoor air, respectively.

China

Li et al. [60] evaluated health risk levels of different age groups of residents living in the vicinity of a MSWI. The carcinogenic risk values of PCDD/Fs in surrounding atmosphere and soil for children, teenagers, and adults were 1.24E-06, 9.06E-07, and 4.41E-06, respectively, suggesting that the potential cancer risk occurred, but the risk was at acceptable levels for both children and adults (<1.00E-05), being the cancer risk for teenagers negligible (<1.00E-06). On the other hand, Liu et al. [61] assessed the health risks faced by local residents, based on the results of dioxin detection in the surrounding area of a waste incineration plant in Beijing. Under all exposures, the lifetime risk of cancer for residents around the incinerator was under the upper end of the range of acceptability (10(-4)). In turn, Li et al. [62] investigated airborne PBDD/Fs and PCDD/Fs around a large-scale MSWI. The bioassay-derived TEQs based on the aryl hydrocarbon receptor activation of airborne

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dioxins around the MSWI were one or two orders of magnitudes higher than their concentration-based TEQs. The corresponding carcinogenic risks at some MSWI-vicinal sites exceeded the acceptable threshold proposed by the US EPA (10-6 ~ 10-4), recommending continuous attention. Recently, Yu et al. [63] measured PCDD/F concentrations in indoor air and indoor dust samples obtained from households near a MSWI. The carcinogenic risks of PCDD/Fs for age groups residing near the MSWI were all less than the risk threshold (10-5). Huang et al. [64] examined the potential health risks posed by the operation of 96 waste-to-energy (WtE) plants in 30 cities in the Bohai Rim of China. The results indicated that cancer risks (were generally low, with values below the accepted threshold of 1.0 × 10-6.

Vietnam

Nguyen et al. [65] characterized concentrations and congener profiles of seven di- to hexachlorinated benzenes (CBzs) in samples collected from one medical waste incinerator (MEWI) and one MSWI in northern Vietnam. Daily intake doses and cancer risks of ash-bound CBzs estimated for workers in the two incinerators were generally lower than critical values. However, cancer risks caused by other relevant pollutants (e.g., polycyclic aromatic hydrocarbons, polychlorinated biphenyls, and dioxin-related compounds) were not considered.

Table 2. Summary of American and Asian Studies on Cancer and Waste Incinerators.

Country	Kind of Study	Population Studied	Highlights	Reference
USA	Risk Assessment	General population near MSWIs	Lifetime cancer risk from PCDD/Fs ranged from 1.8×10^{-7} to 6.7×10^{-6}; deemed low.	Nessel et al. [49]
USA	Case-Control	NHL cases in SEER registries	No overall NHL risk near MSWIs; reduced risk observed near modern incinerators.	Pronk et al. [51]
USA	Cohort	Nurses' Health Study II participants	Increased breast cancer risk for women living within 10 km of MSWIs, stronger within 5 km.	VoPham et al. [52]
Canada	Risk Assessment	Residents near Ontario WTE facility	No significant cancer risks from facility emissions.	Ollson et al. [56]
Japan	Risk Assessment	Residents near MSWIs and heavy fish consumers	PCDD/Fs posed neurobehavioral risks to infants/fetuses; cancer risks acceptable for adults.	Yoshida et al. [57]
Taiwan	Exposure Assessment	Workers and residents near two MSWIs	Workplace PCDD/F levels 5–15x higher than outdoor air.	Shih et al. [59]
China	Risk Assessment	Residents near Beijing MSWI	Lifetime cancer risk $<10^{-4}$ (acceptable).	Liu et al. [61]
China	Environmental Monitoring	Residents near MSWI in Bohai Rim cities	Cancer risks (CR) below 1.0×10^{-6} for 96 WtE plants.	Huang et al. [64]
Vietnam	Exposure Assessment	Workers at medical and municipal waste incinerators	Low cancer risks from ash-bound CBzs; other pollutants not assessed.	Nguyen et al. [65]

6. Discussion

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The studies above summarized provide a comprehensive overview of research conducted in various countries to assess the potential cancer risks associated with residential proximity to MSWIs. These studies span several decades and employ diverse methodologies, offering valuable insights into the complex relationship between MSWI emissions and cancer incidence (see Table 1 and Table 2). The research methodologies used in these studies have evolved over time, reflecting advancements in epidemiological techniques and exposure assessment. Early studies often relied on simple distance-based approaches, while more recent investigations have incorporated sophisticated dispersion modeling, biomonitoring, and advanced statistical analyses. This progression has allowed for more accurate exposure assessments and better control of confounding factors.

However, several methodological challenges persist. Accurately quantifying individual exposure to MSWI emissions remains difficult, particularly for historical exposures. The long latency periods for many cancers complicate the establishment of causal relationships with MSWI emissions. Socioeconomic status, lifestyle factors, and other environmental exposures can significantly influence cancer risk, making it challenging to isolate the effects of MSWIs. The results across studies show some inconsistencies. Several studies, particularly in Italy and France, found increased risks for STS and NHL near MSWIs with high PCDD/F emissions. However, other studies found no significant associations. In turn, some studies, suggested an increased risk of liver cancer, but concerns about misdiagnosis and residual confounding were raised. Various studies also reported potential associations with lung, larynx, and breast cancers, but findings were not consistent across all investigations.

An important consideration is the temporal aspect of these studies. Many investigations focused on older MSWIs, with higher emission levels of carcinogenic pollutants. More recent studies, particularly those examining modern facilities with advanced pollution control technologies, generally reported lower risks. This trend highlights the importance of technological advancements in mitigating potential health risks. Although there are studies which consistently identified food ingestion as the primary exposure pathway for metals, PCDD/Fs and related compounds, the relative contributions of MSWI emissions to overall exposure remain debated, given the presence of other environmental sources. Risk assessments generally found that cancer risks associated with MSWI emissions were within or below regulatory thresholds, especially for modern facilities. Nevertheless, some studies identified potentially elevated risks for specific subgroups or under certain exposure scenarios. The studies have also revealed some geographical variations in findings, which may reflect differences in regulatory standards, waste management practices, and environmental conditions across countries.

Environmental Justice Considerations

The reviewed studies underscore also the critical intersection of environmental justice and cancer risks associated with residential proximity to MSWIs. Historically, marginalized communities, including low-income and minority populations, have been disproportionately burdened by the siting of waste incinerators and other polluting facilities, often due to systemic inequities in land-use planning and regulatory enforcement. These populations face elevated exposure to carcinogenic emissions from older, poorly regulated MSWIs, exacerbating existing health disparities. Furthermore, socioeconomic factors such as limited access to healthcare, higher prevalence of preexisting conditions, and cumulative exposure to multiple environmental hazards amplify risks in these communities. While advancements in incinerator technology have reduced the emissions of toxic (carcinogenic and non-carcinogenic) pollutants in some regions, disparities persist where outdated facilities remain operational in vulnerable areas. Addressing these inequities requires policies prioritizing the phase-out of high-emission incinerators in overburdened communities, equitable public health interventions, and inclusive decision-making processes to ensure that the benefits of the most recent waste management technologies do not come at the expense of marginalized groups. Environmental justice must remain central to future research and policymaking to mitigate historical harms and prevent new inequities in the transition toward sustainable waste management.

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While historical evidence suggests potential cancer risks associated with older MSWIs, modern facilities operating under strict emission controls appear to pose lower risks. However, given the complexity of the issue and the potential for long-term health effects, continued research and monitoring are necessary to ensure the protection of public health in communities near MSWIs. Clear communication of research findings to the public is essential, considering the often complex and sometimes inconsistent nature of the evidence.

7. Conclusions

Based on the reviewed studies, several key conclusions can be drawn. 1) Historical evidence: there is some evidence suggesting increased cancer risks, particularly for STS and NHL, associated with older MSWIs that had high PCDD/F emissions. However, these findings are not consistent across all studies. 2) Modern facilities: more recent studies on modern MSWIs -with advanced pollution control technologies- generally reported lower risks, often within acceptable regulatory limits. 3) Specific cancer types: while some cancer types (e.g., STS, NHL, liver) have been more frequently associated with MSWI proximity, the evidence is not fully conclusive. Thus, further research is needed to establish causal relationships.

Although advancements in exposure assessment and statistical techniques have improved the quality of research, challenges remain in accurately quantifying individual exposures and controlling for confounding factors. While historical evidence suggests potential cancer risks associated with older MSWIs, modern facilities operating under strict emission controls appear to pose lower cancer risks. Anyhow, in 2025, the continued operation of installations like MSWIs that emit carcinogenic substances such as PCDD/Fs, arsenic, cadmium, and hexavalent chromium (among others), is unacceptable, even when emissions are regulated. The concept of "safe limits" for carcinogenic substances is fundamentally flawed, as no level of exposure can be considered entirely without risk. As an example, it is now well established that smoking even one cigarette per day does not guarantee immunity from lung cancer [66].

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: No new data were created or analyzed in this study. Data sharing is not applicable to this article.

Conflicts of Interest: The author declares no conflicts of interest.

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