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Health Effects due to Emissions from Energy from Waste Plant in London

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Executive Summary

This report considers the health effects associated with emissions from energy from waste (EfW) facilities in London. The principal objectives of the study were to:

- Undertake a detailed literature review to collate the evidence regarding health effects associated with emissions from EfW; and
- Assess the effects of emissions of NOx and $PM_{2.5}$ on ambient air quality to establish the magnitude and geographical spread of the impacts and to quantify the effects on human health based on the exposed population and established risk factors.

Literature Review

This study reviewed the recently published (i.e. in the last five years) scientific literature to identify any potential direct effects of modern EfW plant (including Municipal Solid Waste Incinerators or MSWIs) on human health, in the community that would be relevant to London. The literature searches identified 35 relevant studies published in the last five years, which have mainly focused on levels of pollutants, such as dioxins and metals, emitted from incinerators, and the assessment of related population exposure and health risks.

The reviewed evidence suggests that well-managed modern EfW/MSWIs are unlikely to pose a significant health risk (i.e. cancer, non-cancer, pregnancy, birth and neonatal health) in the UK under the current stringent regulatory regime. Recent epidemiological studies (i.e. population based) have not found consistent evidence of health effects associated with modern EfW/MSWIs. However, risk assessment studies (i.e. based on mathematical calculations) have in some cases, mainly in China, estimated cancer risks that exceed recommended ranges. The comparability of the plants included in these studies with modern EfW/MSWIs currently operating in the UK is, however, unclear.

Recent epidemiological studies did not find evidence of an association between EfW/MSWIs in Great Britain and infant mortality, adverse pregnancy, birth or neonatal outcomes. However, one of these studies found small excess risks associated with congenital heart defects and genital anomalies in proximity to MSWIs. These latest findings may reflect incomplete control for confounding factors, but a possible causal effect could not be excluded.

Earlier studies did not find convincing evidence of an association of proximity to older municipal waste incinerators in Great Britain with cancer. Although there is limited evidence of an association of proximity to older incinerators, or exposure to dioxins, with sarcoma and lymphoma risk in other countries, the very substantial decrease in dioxin emissions from EfW/MSWIs over recent years is likely to make these risks negligible for populations currently living in the vicinity of modern, well-controlled plants in the UK. It is important to point out that stack emissions from modern MSWIs are much reduced compared to old generation plants.

On the basis of this literature review, it is concluded that any potential health risks associated with direct emissions from modern, effectively managed and regulated EfWs in London are exceedingly low.

Impacts of EfW Emissions on Concentrations of Nitrogen Dioxide and Particulate Matter and Associated Health Effects

The second part of the study has quantified the health effects associated with emissions of nitrogen oxides and fine particulate matter from five facilities in London using established risk factors. Dispersion modelling of emissions from the facilities has been carried out; making use of on-site emissions measurements reported to the Environment Agency where available. The dispersion model results have been combined with published (2017/2018) demographic information, and with exposure-response coefficients published by Defra in 2019, in order to calculate the number of deaths brought forward by emissions from the five facilities. Hospital admissions for respiratory and cardiovascular conditions which are associated with particulate matter emissions have also been calculated.

The contribution of the facilities to annual mean concentrations of nitrogen dioxide and particulate matter is greatest close to the facilities. There is also a general trend of higher EfW-related concentrations in the east of London, reflecting both the prevailing wind directions and the spatial distribution of the facilities.

The spatial gradient in concentrations combines with spatial demographic patterns to cause a clear east-west gradient in both mortality and hospital admissions attributable to emissions from the facilities. For example, the number of deaths brought forward per capita is more than eight times higher in Havering than it is in Hillingdon. Furthermore, more than half of all deaths within London attributable to emissions from the EfW facilities are predicted to occur within just nine boroughs (Havering, Croydon, Bexley, Bromley, Greenwich, Barking and Dagenham, Redbridge, Lewisham, and Southwark).

In total, 15 deaths of London residents per year are calculated to be attributable to emissions of nitrogen oxides and particulate matter from the five EfW facilities. For hospital admissions, less than one per year for both respiratory and cardiovascular conditions is calculated to be attributable to particulate matter emission from the five EfW facilities.

The study only covers the effects within London that are attributable to the five EfW facilities identified for this study, and excludes facilities peripheral to London.

1 Introduction

1.1 Air Quality Consultants Ltd (AQC) has been commissioned by the Greater London Authority (GLA) to undertake a study related to the impacts of Energy from Waste (EfW) facilities in London on air quality and human health. The principal objectives of the study are to:

- understand the evidence regarding health effects associated with emissions from EfW; and
- assess the effects of emissions of NOx and $PM_{2.5}$ on ambient air quality to establish the magnitude and geographical spread of the impacts and to quantify the effects on human health based on the exposed population and established risk factors.

1.2 The literature review on the evidence of health effects was undertaken in association with the Institute of Occupational Medicine (IOM) and is summarised in Section 2 of this report. The assessment of the effects of emissions on air quality and human health is described in Section 3.

2 Health Effects Associated with EfW – Literature Review

Introduction

2.1 A detailed literature review of the health effects associated with emissions from EfW plant was carried out by the Institute of Occupational Medicine. The full report is included in Appendix 3, which also includes full details of the references cited. This section provides a summary of the scope of the study, the methodology and the conclusions.

2.2 Whilst this study is focussed on EfW plant, the literature review has also considered emissions from Municipal Solid Waste Incinerators (MSWIs) as the technologies are essentially the same, and the terms are considered inter-changeable for the purpose of this study. The study has not considered other types of incineration such as hazardous or clinical waste as these are outside of scope.

2.3 It is widely accepted that emissions from modern incineration plant are much lower than from older plant, and for this reason older studies were excluded from the review. The study has reviewed recently published (i.e. in the last five years) scientific literature to identify any potential impacts of modern EfW. Additional papers identified by GLA were also included although they fall outside of this time window, namely: the British Society for Ecological Medicine report on the health effects of waste incinerators (Thompson and Anthony, 2008) and subsequent responses by the Health Protection Agency and Enviros. The search string for the review was based on the terms described in Table 1.

2.4 Based on the inclusion and exclusion criteria, the papers were screened independently by two reviewers on the basis of their title and abstract (where available) to identify studies of relevance. Inappropriate titles/abstracts were filtered out of the list of publications identified for full-text scanning. In all cases a conservative strategy was adopted where, if the relevance or otherwise of a paper was not apparent from the title and/or abstract, the paper was retained for full text scanning and possible review. A random sample of 10% of papers was independently checked by a third reviewer and the results compared for quality assurance purposes. Any discrepancies were resolved by discussion among the three reviewers.

Table 1: Scope of Study

Population	Human, Individual, Population
Exposure	Proximity, Distance, Spatial variability, Energy and waste, Incineration, Thermal/heat treatment of waste, Municipal solid waste incineration (MSWI), Municipal solid waste (MSW), Waste management, Waste to energy (WTE), Energy from waste (EfW), Mechanical biological treatment (MBT), Advanced thermal technologies (ATT), Emissions, Exposure, Air pollution, Air quality, Particulate matter, PM, PM_{10}, $PM_{2.5}$, Nitrogen dioxide, NO_2, Nitrogen oxides, NO_x, Sulphur dioxide, SO_2, Polycyclic Aromatic Hydrocarbons, PAH, Polychlorinated biphenyls, PCB, Heavy metal, Dioxin, Hydrogen chloride, HCl, Carbon monoxide, CO, Volatile Organic Compounds, VOCs, Persistent Organic Pollutants, POPs, Polychlorinated dibenzo-p-dioxins/ furans (PCDD/Fs), Polychlorinated biphenyls (PCBs), Mercury, Furans, Phthalates, Ketones, Aldehydes, Organic acids, Alkenes, Ultrafine particles, Organochlorines, Fly ash.
Health Outcomes	Disease, Illness, Mortality (all cause), Respiratory mortality, Respiratory morbidity, Inflammatory response, Asthma, Exacerbations, Symptoms, Chronic Obstructive Pulmonary Disease (COPD), Cardiovascular mortality, Cardiovascular morbidity, Cardiac symptoms, Cardiac parameters, Cancer, Mental health, Cognition, Dementia, Diabetes, Prenatal effects, Birth weight, Intrauterine growth, Hospital admissions, Primary care visits, GP visits, Disability-adjusted life-years, Quality-Adjusted Life-Years (QALYs).
Types of Studies	Systematic reviews, Reviews, Observational studies, Modelling studies, Exposure assessment.
Inclusion Criteria	Papers published in the last 5 years; In English language; UK and International evidence; Scientific literature; Grey literature.
Exclusion Criteria	Papers published more than 5 years ago; Papers not in English; Studies not related to Energy from Waste incineration; Studies not related to Municipal Solid Waste; Occupational exposure studies; Studies relating to radioactive or clinical waste; Life Cycle Analysis (LCA) studies.

2.5 An adapted version of the NICE public health guidance Quality Appraisal Checklist for quantitative intervention studies (NICE, 2012) was used to derive a quality assessment summary checklist, designed to:

"appraise a study's internal and external validity after addressing the following key aspects of study design:

- *characteristics of study participants*
- *definition of, and allocation to, intervention and control conditions*
- *outcomes assessed over different time periods*
- *methods of analyses."*

2.6 The 'quality assessment summary' was scored using '++', '+' or '−' and recorded in the data extraction spreadsheet.

++ For that aspect of study design, the study has been designed or conducted to minimise the risk of bias.

+ Either the answer to the checklist question is not clear from the way the study is reported, or the study may not have addressed all potential sources of bias for that particular aspect of study design.

− For aspects of the study design in which significant sources of bias may persist.

Summary Conclusions

2.7 There have been many published studies assessing the impact of MSWIs on the environment and human health in different countries. This review identified 35 relevant studies published in the last five years mainly focused on levels of pollutants (PCDD/Fs, metals, etc.) in the air and soil around incinerators, and the assessment of related population exposure and health risks (cancer and non-cancer). Most of these studies came from China and Spain. There have been very few original epidemiological studies, three from the UK and three from Italy (Freni-Sterrantino et al. 2019; Ghosh et al. 2019; Parkes et al. 2019; Candela et al. 2015; Vinceti et al. 2018; Santoro et al, 2016) published within this period, focusing on adverse pregnancy, birth and neonatal outcomes. Earlier epidemiological studies mainly focused on adult cancers (Elliot et al. 1996; 2000), but the review did not find any relevant epidemiological studies on cancer published in the last five years.

2.8 This study identified six literature reviews of varied quality published within the last five years (Ashworth et al., 2014; Jones and Harrison, 2016; Zhang et al., 2016; Wielgosiński and Targaszewska, 2014; Ncube et al., 2017; Johnson, 2016). However, three of these reviews focused on emissions from MSWIs rather than on health effects (Jones and Harrison, 2016; Johnson, 2016; Zhang et al., 2016). Earlier literature reviews that examined health effects associated with different solid waste management options, including incineration, were published by Crowley et al. (2003), Porta et al. (2009), Rushton (2003), Franchini et al. (2004), Hu and Shy (2001), and Thompson and Anthony (2008). Evidence from these earlier reviews is not formally included in this report, but some of their findings were discussed in the more recent, high quality review by Ashworth et al. (2014).

2.9 The British Society for Ecological Medicine report on the Health Effects of Waste Incinerators (Thompson and Anthony, 2008), argued that:

(a) incinerators are a major source of fine particulates, of toxic metals and organic chemicals, including known carcinogens, mutagens, and hormone disrupters;

(b) epidemiological studies have shown higher rates of adult and childhood cancer and birth defects around municipal waste incinerators.

In the recent scientific literature examined (published in the last five years), there was no consistent evidence supporting either of these two statements in relation to modern MSWIs. Modern plant operating in the UK under the Industrial Emissions Directive have very low emissions to the environment that may only marginally increase population exposure to pollutants and related health risks.

2.10 The reviewed epidemiological evidence in relation to cancer, points at significant increases in sarcomas and lymphomas cases associated with exposure to dioxins from old (pre-2000) waste incinerators in Italy (Zambon et al. 2007; Biggeri and Catelan, 2005) and Spain (Garcia-Perez et al., 2013). However, dioxin levels were not generally monitored as part of these studies, and therefore exposures were only estimated approximately. More recent studies have shown very significant decreases in exposure to organochlorines (including PCDD/Fs and PCBs) near modern MSWIs (post-2005) (Zubero et al., 2017).

2.11 A number of recent exposure/risk assessment studies, mostly from China, have estimated cancer risk based on measured or modelled exposures to heavy metals (Ma et al., 2018), PAHs (Jia et al., 2017), and PCDD/Fs (Ho et al. 2016), using Incremental/Excess Lifetime Cancer Risk (I/ELCR) calculation approaches. The calculated I/ELCR were in several cases in exceedance of the acceptable levels of 1.0×10^{-6} to 1.0×10^{-4} (Ma et al., 2018; Jia et al., 2017), particularly downwind from the incineration plants (Ho et al., 2016). However, these exposures were also related to pollution sources other than incineration (e.g. industry, energy generation), and multiple exposure pathways (ingestion, dermal, inhalation) for heavy metals and PAHs. Health risks associated with MSWIs may not be limited to direct exposure to air and soil pollution. For example, consumption of locally grown food may be a significant exposure route to PCDD/Fs and heavy metals such as mercury from MSWIs (Deng et al., 2016). Lower cancer risks associated with PCDD/Fs exposure from incinerators were estimated in two studies from East China (Li et al., 2016) and Italy (Scungio et al., 2016).

2.12 Although there is limited information about the specific MSWI plants studied in China, it is unlikely that they operated under a similarly stringent regulatory regime as the one that currently applies to MSWIs in the UK. Based on the reported exposures and risks estimates, and the declining MSWI emission trends overall, it is concluded that the direct cancer risks associated with modern MSWIs in the UK are currently very low. However, given the relatively high PCDD/Fs levels in soils around MSWIs found in other countries, it is plausible that legacy contamination from older MSWIs could affect current population exposure levels due to soil re-suspension or ingestion. Furthermore, bearing in mind that the minimum induction periods for cancers is generally 10 years for solid tumours and 1 year for leukaemia (Garcia-Perez et al., 2013), it may take a number of years for new epidemiological evidence to emerge in relation to modern MSWIs.

2.13 Earlier epidemiological studies examining adverse pregnancy, birth and neonatal outcomes have shown association of MSWIs emissions with a number of outcomes, including neural tube and heart defect, facial clefts and urinary tract defects, and miscarriages and preterm deliveries. However this evidence is inconsistent and related to older plants. The recent, high quality studies in Great Britain (Ghosh et al., 2019; Freni-Sterrantino et al., 2019; Parkes et al. 2019) did not find evidence of an association between emissions from MSWIs and adverse pregnancy, birth or neonatal outcomes. However, Parkes et al. (2019) found small excess risks associated with congenital heart defects and genital anomalies in proximity to MSWIs. These latest findings may reflect incomplete control for confounding, but a possible causal effect could not be excluded.

2.14 Primary emissions from well-managed modern MSWIs with appropriate air pollution abatement technologies are generally very low compared with to other outdoor sources of the same pollutants (Buonanno and Morawska, 2015; Johnson, 2016; Jones and Harrison, 2016). However, emissions of secondary particulate matter from MSWIs is a topic that would benefit from further research. The current legislative regime minimises the potential for population exposure to MSWI emissions; however if exceedances of emission limits occur, this may pose a health risk to exposed populations.

2.15 It is, therefore, recommended that exposure assessment methods include atmospheric dispersion modelling with realistic emission estimates, including from potential increases in heavy duty traffic, and consider multiple exposure pathways (Ashworth et al., 2014). Additionally, multi-site MSWI studies with clearly defined health outcomes and validation of exposure through human biomonitoring are recommended in order to increase confidence in the epidemiological findings.

3 Impacts of EfW Emissions on Ambient NO_2 and $PM_{2.5}$

Introduction

3.1 This Section considers the burden of mortality and increases in hospital admissions associated with emissions of nitrogen oxides (NOx, following their conversion to nitrogen dioxide (NO_2)) and fine particulate matter (PM_{10} and $PM_{2.5}$) from five energy from waste (EfW) facilities in London. It has been produced by Air Quality Consultants Ltd. on behalf of the Greater London Authority (GLA).

3.2 The facilities which were identified by GLA are shown in Figure 1. They are:

- South East London Combined Heat and Power (SELCHP), Lewisham SE14 5RS
- Cory Riverside Resource Recovery, Belvedere DA17 6JY
- Viridor Beddington Energy Recovery Facility, Sutton CR4 4JG
- Thames Gateway Energy Generation Facility (proposed), Dagenham RM9 6BF
- Edmonton EcoPark ERF (proposed upgraded facility), Edmonton N18 3AG

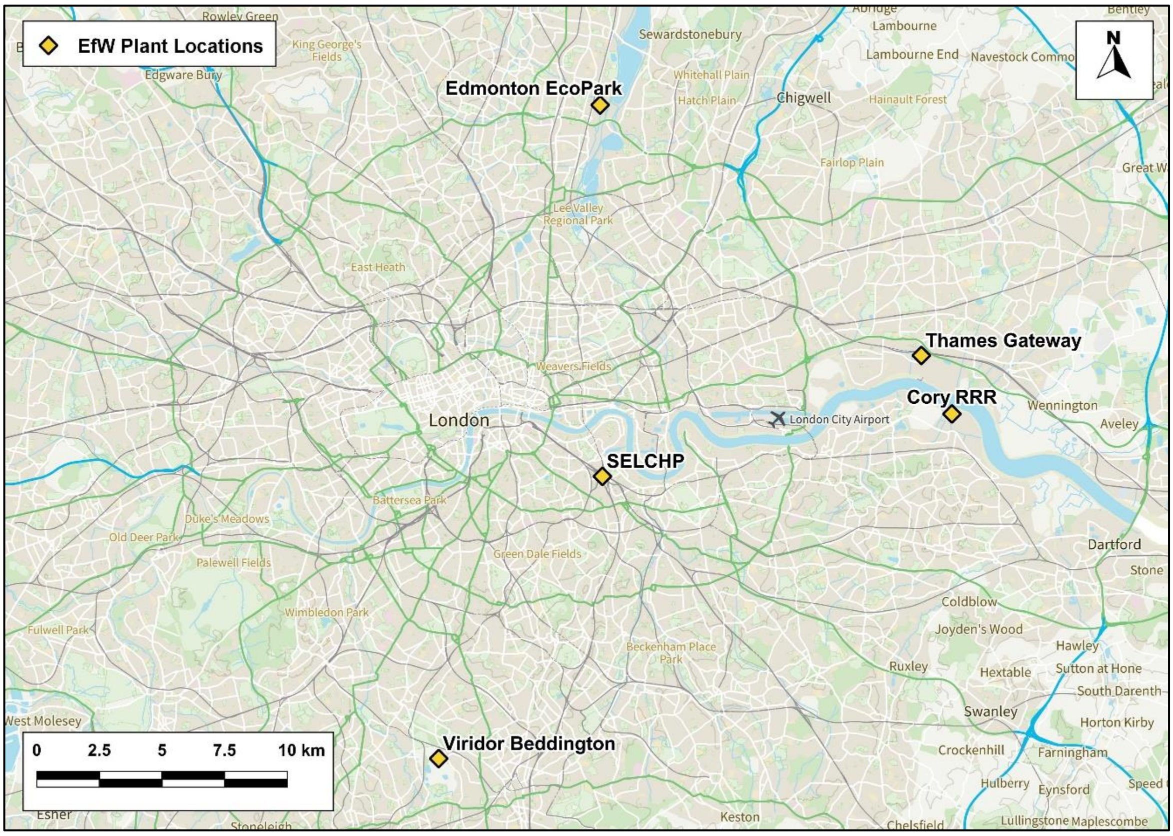

Figure 1: Locations of the EfW Plant Included in the Study

3.3 The SELCHP and CORY RRR facilities have both been operating for a number of years (opening in 1994 and 2012 respectively). The Viridor Beddington facility opened much more recently, such that records are only available for a few months of operation. The Edmonton facility is currently being built, and will replace an existing facility of the same name. The Thames Gateway facility is not yet operational.

3.4 While air quality modelling had previously been carried out for each of these sites in support of planning permission and environmental permits, this was based on maximum emissions limits rather than typical, or expected, operational emissions. As such, while the outputs from those studies can be considered to provide an upper-bound to the ambient concentrations arising from each site, they will not accurately represent the impacts. Care has thus been taken, within this current study, to determine the actual, or likely, emissions from each site. It should also be recognised that the planning permissions and permits were based on comparing predicted concentrations of NO_2 and particulate matter against air quality standards. There was no requirement to calculate potential health outcomes from exposure below these standards.

3.5 The health effects related to urban air pollution include mortality, cardiovascular and respiratory hospital admissions, lung cancer, diabetes, chronic heart disease, stroke, asthma and chronic bronchitis. This assessment has focussed on mortality and hospital admissions, as these are the outcomes for which Defra reports a strong association (Ricardo Energy and Environment, 2019). With respect to hospital admissions, the evidence is strongest for cardiovascular and respiratory effects and so these have been quantified.

3.6 There is a strong body of evidence that adverse health effects are associated with exposure to $PM_{2.5}$, with no recognised threshold below which there are no effects. There is also a growing body of evidence that exposure to NO_2 is associated with adverse effects, again with no recognised threshold. It is though difficult to disentangle the effects of $PM_{2.5}$ and NO_2 in epidemiological studies, and it is not appropriate to treat the effects as additive when they are based on calculations using single pollutant risk coefficients. The approach taken here has thus been to calculate the total mortality attributable to the emissions separately for both pollutants from the facilities and not to associate this with any specific pollutant.

3.7 Over large population groups, even very small increases in concentrations can lead to a statistical increase in mortality and/or hospital admissions. This study has thus considered the entire population of the Greater London urban area.

3.8 The study considers primary emissions only. It does not take account of the potential for gaseous emissions from the facilities to form particulate matter via chemical reactions in the atmosphere, although this is unlikely to make a significant difference to the outcome within London due to the relatively slow rate of these reactions. The outcomes are based on demographic information and mortality data specific to London, together with national rates of hospital admissions (as London specific data are not available), for 2017/2018, combined with the latest exposure-response coefficients, published in 2019. More recent changes to population metrics are not considered.

Dispersion Modelling Methodology

Emissions Rates

3.9 Emissions rates of nitrogen oxides (NOx)[1] and total particulate matter (PM) for SELCHP and Cory Riverside have been taken from the monthly reports of continuously monitored emissions to air, obtained from the Environment Agency. These are produced as a condition of the facilities' environmental permits and provide daily-mean (SELCHP) and monthly-mean (Cory Riverside) emissions rates. It was not possible to obtain more temporally-refined data.

3.10 Emissions released at different times of day and year are subject to different dispersion conditions. This is because ambient temperature and other meteorological conditions follow distinct diurnal and seasonal patterns. The principal effect of this temporal variation when running dispersion models tends to be seen on a diurnal basis. However, it has not been possible to differentiate between emissions on a sub-daily resolution. Furthermore, a review of the daily-mean and monthly-mean emissions rates for the three years 2016-2018 revealed that they were highly consistent over this entire period. It has considered that there is no added value in differentiating between emissions released on different days or months of the year (i.e. over this time resolution, emissions were essentially constant). An average emission rate (in mg/Nm^3) has thus been calculated from the three years of records from each emission source[2].

3.11 Long-term stack-monitoring records were not available for the remaining three facilities (Beddington, Thames Gateway, and Edmonton); either because the sites are not yet operational, or because they only recently began operation. It is thus necessary to estimate the likely emissions. Before becoming operational, a facility must obtain a permit from the Environment Agency. These permits set emissions limits for both NOx and PM, which are values which the plant must not exceed. Typically, emissions of PM from EfW facilities tend to be much lower than the permitted limits, while emissions of NOx are much closer to those limits. This trend has also been observed in the SELCHP and Cory Riverside emissions measurements.

3.12 The permits for the facilities were obtained from the Environment Agency, where available. All of the permits specify the same emissions limits (in g/Nm^3) for PM. It has thus been assumed that the PM emissions (in g/Nm^3) from the Beddington, Thames Gateway, and Edmonton facilities will

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1 NOx is the term for the sum of nitrogen dioxide (NO_2) and nitric oxide (NO). Most emissions are in the form of NO, but NO reacts with ozone in the atmosphere to form NO_2.

2 Nm^3 refers to 'Normal' cubic metre. In this report, 'N' is used to refer to conditions recorded in the absence of moisture, at 11% oxygen, and at 0 degrees C.

be the same as those measured at Cory RRRR (the newest facility for which measured emissions data are available)[3].

3.13 For NOx, the newer facilities are required to operate under stricter emissions limits than the older facilities. The daily mean NOx emissions limit is set at 200 mg/Nm^3 for both SELCHP and Cory RRR, while for Beddington it is 165 mg/Nm^3 and for Edmonton it is 80 mg/Nm^3. As far as it has been possible to determine, the Thames Gateway facility has not yet been granted a permit. It has thus been assumed that the Beddington site will emit constantly at its daily mean NOx emission limit of 165 mg/Nm^3, while the Edmonton and Thames Gateway facilities will both emit constantly at 80 mg/Nm^3; thus assuming that the permit for Thames Gateway matches that for Edmonton. This approach risks over-predicting NOx emissions from these facilities but, in the absence of on-site measurements, represents the most pragmatic approach. Similarly, if the permits held by SELCHP or Cory RRR are revised in the future, necessitating lower emissions from these facilities, then this assessment will have overstated NOx emissions.

Stack Release Conditions

3.14 For SELCHP and Cory RRR, exhaust temperatures and flow rates have been taken from site-specific measurements collated by the Environment Agency for the same 3-year (2016-2018) period as the emissions measurements.

3.15 For the remaining three facilities, it has been necessary to rely on the release conditions used in the modelling carried out for the planning and permitting of each facility. The release conditions used in the modelling will have reflected the intended operating conditions of the plant. They have been taken from the following sources:

- Viridor Beddington ERF – Surrey Waste Local Plan 2018-2033 Appendix C to the Habitat Regulations Assessment Report (Surrey County Council, 2019)
- Thames Gateway – Air Quality Assessment of Emissions to Atmosphere from the Proposed Thames Gateway Energy Generation Facility P1810 (ADM Ltd, 2018)
- Edmonton ERF – North London Heat and Power Project – Environmental Statement: Volume 2 Appendices 2.1 to 5.10 (Arup and North London Waste Authority, 2015)

Assumed Operating Parameters

3.16 The calculated emissions (in mg/Nm^3) from each emission point were multiplied by the flow rates (in Nm^3/s) to provide emission rates in g/s. The assumed operating parameters for each site are set out in 2.

[3] Note that assuming the same emission rate in g/Nm^3 is not the same as assuming the same mass emission rate (e.g. in g/s) since the exhaust volume (which relates closely to the waste throughput of each facility) is different for each site (see Table).

Table 2: Assumed Operating Parameters

	SELCHP	Cory Riverside Resource Recovery	Viridor Beddington	Thames Gateway	Edmonton ERF
Capacity (kt-waste/yr)	420	575	275	200	700
Number of Emission Points	2	3	2	2	2
Actual Flow Rate (m^3/s)	95	58	40.9	28.6	84.2
Exhaust Gas Temperature (°C)	151	130	140	140	100
Flue Diameter (m)	2.4	2.27	1.9	1.10	2.67
Exit Velocity (m/s)	22	14.3	15.8	30	15
Stack Height (m)	100	90	85	55	100
NOx Emission Rate (from each emission point) (g/s)	8.300	7.628	4.719	2.140	5.420
	8.408	7.612	4.719	2.140	5.420
		7.514			
PM Emission Rate (from each emission point) (g/s)	0.054	0.189	0.135 [a]	0.098 [a]	0.344 [a]
	0.075	0.192	0.135 [a]	0.098 [a]	0.344 [a]
		0.185			

[a] Emission rate derived from Cory Riverside Resource Recovery, factored by volumetric flow rate.

Dispersion Modelling

3.17 Pollutant concentrations have been predicted using the ADMS-5 dispersion model, which incorporates a state-of-the-art understanding of dispersion processes within the atmospheric boundary layer. The model has been run to predict the contribution of the facilities to annual mean concentrations of both nitrogen oxides and PM.

3.18 The urban canopy flow module has been used in the model. This calculates the changes in the vertical profiles of velocity and turbulence caused by the presence of buildings in an urban area. The input data are published by Cambridge Environmental Research Consultants (CERC, 2016), who developed the ADMS model.

3.19 Hourly sequential meteorological data from Heathrow Airport have been used in the dispersion model. This is deemed the most representative meteorological monitoring station for conditions in Greater London. The model parameters for the Heathrow monitoring station are provided in Table 3. The model has been run using five years of meteorological data (2014 to 2018) and used to calculate a mean concentration over the full five years of meteorology. This represents a difference from the approach which would usually be undertaken for planning or permitting, which would seek to identify the worst-case meteorological dataset and thus provide an upper-bound, rather than intentionally-representative results. The intention of the current study is to predict the most likely impacts rather than an upper-bound.

Table 3: Assumed Meteorological Parameters for the Heathrow Monitoring Station

Parameter	Input Value
Surface Roughness	0.2
Minimum Monin-Obukhov Length (m)	30
Surface Albedo	0.23

Receptors

3.20 The model has been run to calculate the concentration of pollutants at discrete receptor points across Greater London. These correspond to population-weighted centroids of the census Output Areas, the lowest geographical level at which census data are provided[4]. These population weighted centroids were provided by the Office for National Statistics.

Total PM to $PM_{2.5}$

3.21 $PM_{2.5}$ denotes airborne particulate matter with an aerodynamic diameter of less than 2.5 micrometres. PM_{10} denotes airborne particulate matter with an aerodynamic diameter of less than 10 micrometres. PM denotes total airborne particulate matter. Thus, PM_{10} is a subset of PM, while $PM_{2.5}$ is a subset of PM_{10}. PM emissions from EfW facilities in the UK are controlled using fabric filters. This type of filter medium has been shown to have a high collection efficiency for large particles (Jones and Harrison (2016)). The available evidence on particle size distributions thus suggests that almost all PM emitted from such facilities is likely to be in the form of $PM_{2.5}$ (and thus also PM_{10}) (Buonanno et al. (2009)). Particle size distributions can change following release from stacks; for example smaller particles may coagulate together to form larger particles. Such effects are not considered in this study. It has thus been assumed that the $PM_{2.5}$ concentration is the same as the total PM concentration, with the same being the case for the PM_{10} concentration.

NO_2:NOx Quotients

3.22 The model has been run to predict the contributions of the facilities to annual mean nitrogen oxides (NOx), which describes the sum of nitric oxide (NO) and nitrogen dioxide (NO_2). Emissions will be predominantly NO, but NO rapidly reacts with ozone in the atmosphere to form NO_2. This reaction is reversible by sunlight, thus NO, NO_2, and ozone exist in a state of dynamic equilibrium, this being the condition found in background air.

4 Each census output area typically contains around 125 households.

3.23 Across the vast majority of the study area, the amounts of NO_2 in NOx will be at ambient background levels. The averaging period of interest to this study is annual mean concentrations. Annual average background NO_2:NOx quotients across the study have thus been investigated. Annual average NO_2 and NOx concentrations at the 26 background listed in Appendix A1 for the three years 2016-2018 have been collated and compared. Inter-site differences are to be expected since the monitors are all subject to different localised effects (while they are all background sites, it is seldom possible in London to get sufficiently far from all NOx emissions sources to avoid any local effects). There is no obvious systematic spatial variation in the NO_2:NOx quotient other than might be attributed to local-scale influences (e.g. proximity to roads etc). Similarly, there are no obvious inter-year differences. It is thus considered most appropriate to take the simple arithmetic mean of all of the recorded annual average NO_2:NOx quotients (with these quotients based on dividing the annual mean NO_2 concentration by the annual mean NOx concentration at each site in each year separately). This average quotient is 0.631, i.e. 63.1% of the NOx is present as NO_2. Five-year mean NO_2 increments from the EfW plant have thus been derived by multiplying the five-year mean NOx increments by 0.631.

Health Impacts Assessment Methodology

3.24 As explained in Paragraph 3.20, the dispersion model has been used to predict the contribution from the facilities to concentrations at the population-weighted centroids of the census Output Areas. The results have been used to derive population-weighted concentration increments.

3.25 Exposure-response coefficients have then been applied to the population in the study area, using the population-weighted increment to concentrations. The risk coefficients have been taken from Defra (Ricardo Energy and Environment, 2019).

3.26 The coefficients are expressed as the Relative Risk per 10 $\mu g/m^3$ of the pollutant (RR10) and are 1.06 for $PM_{2.5}$ attributable mortality, 1.023 for NO_2 attributable mortality, and 1.008 for PM_{10} attributable respiratory and cardiovascular hospital admissions. These are the health outcomes for which Defra states there is strong evidence of an association (Ricardo Energy and Environment, 2019).

3.27 The Relative Risk (RRc) for the population-weighted concentration (c) is then derived as follows: $RRc = RR10^{(C/10)}$. The Attributable Fraction (AF) of the health outcome is derived from the RRc as follows: AF = (RRc – 1)/RRc. The AF is then applied to the base data described below.

3.28 In the case of mortality, the base data are the non-accidental deaths in 2017 for the population over 30 years of age, published for each borough by the Office of National Statistics in 2018 (ONS, 2018).

3.29 For hospital admissions, it has not been possible to obtain data for individual boroughs, so use has been made of the rate of hospital admissions per resident of England in 2017/2018 derived from national admissions data from the NHS (2018)[5].

3.30 The mortality calculations have been carried out for both NO_2 and $PM_{2.5}$. The numbers are greater for NO_2 than for $PM_{2.5}$, thus the results for NO_2 are presented. This follows advice from the Committee on the Medical Effects of Air Pollutants (COMEAP) (2018) that the NO_2 mortality rates based on single pollutant epidemiological models, will reflect exposure to both NO_2 and other pollutants, including $PM_{2.5}$. It is for this reason that the NO_2 and $PM_{2.5}$ results are not treated as additive. The results are thus presented as mortality attributable to air pollution and should not be ascribed to NO_2 alone.

Results

Impacts on Ambient Concentrations

3.31 Figure 2 and Figure 3 show the contributions of the five EfW facilities to annual mean concentrations of NO_2 and $PM_{2.5}$ respectively. Each census output area has been coloured to represent the average concentration/contribution from the facilities[6]. The spatial pattern in concentrations is similar for each pollutant; with the highest concentrations close to the Thames Gateway facility which is likely to reflect the combined local influence of the Thames Gateway facility and the Cory RRR facility to the southwest (see Figure 1). The lowest concentrations are to the west of London, where there are no EfW plant within Greater London[7]. There are some differences in the spatial distribution of each pollutant (reflecting differences in the NOx:PM emissions ratio for each plant). In particular, NO_2 concentrations (Figure 2) are noticeably elevated in the north of Lewisham (close to the SELCHP facility) but $PM_{2.5}$ concentrations are not (Figure 3).

5 NHS hospital episode statistics applied to the population of England and then applied to the future year population estimates. Notwithstanding changes between the base year and the current and future years, this is likely to present a conservative approach, as it is known that the rate of hospital admissions in the London area is less than the national average.

6 These figures appear similar to isopleth maps because each census Output Area is relatively small.

7 Plant outside of London, including the Lakeside facility near Heathrow Airport, are not included in this study.

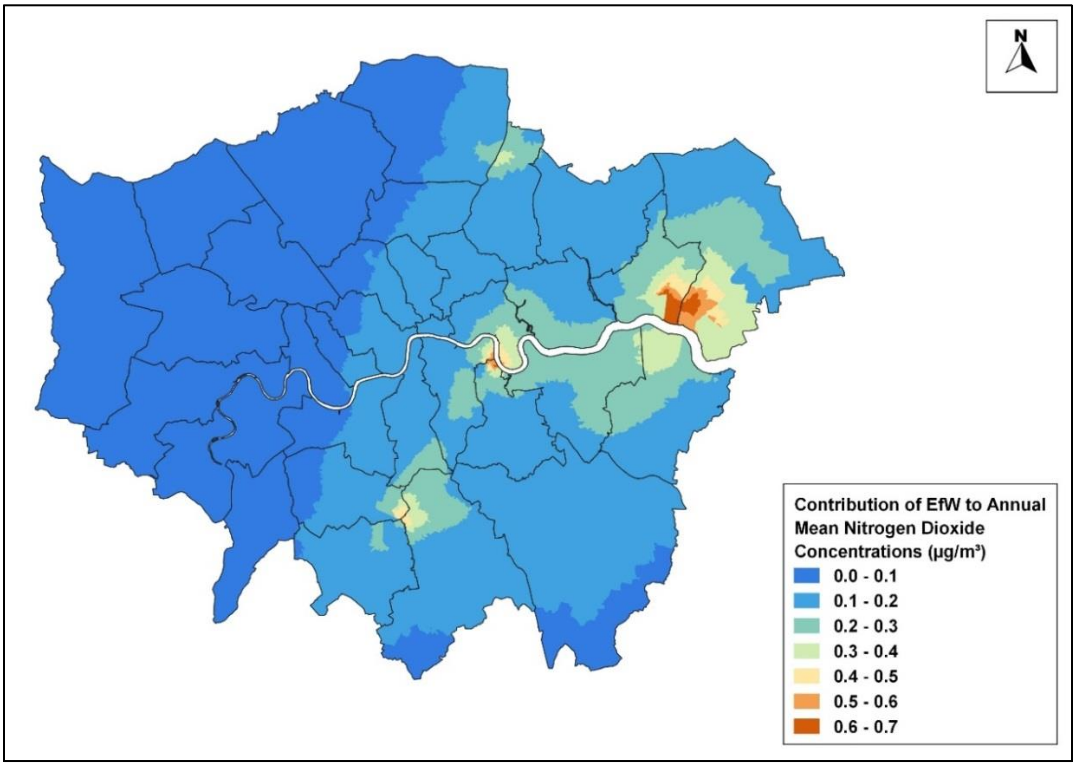

Figure 2: Contribution of Five EfW Facilities to Annual Mean NO_2 Concentrations in each Census Output Area

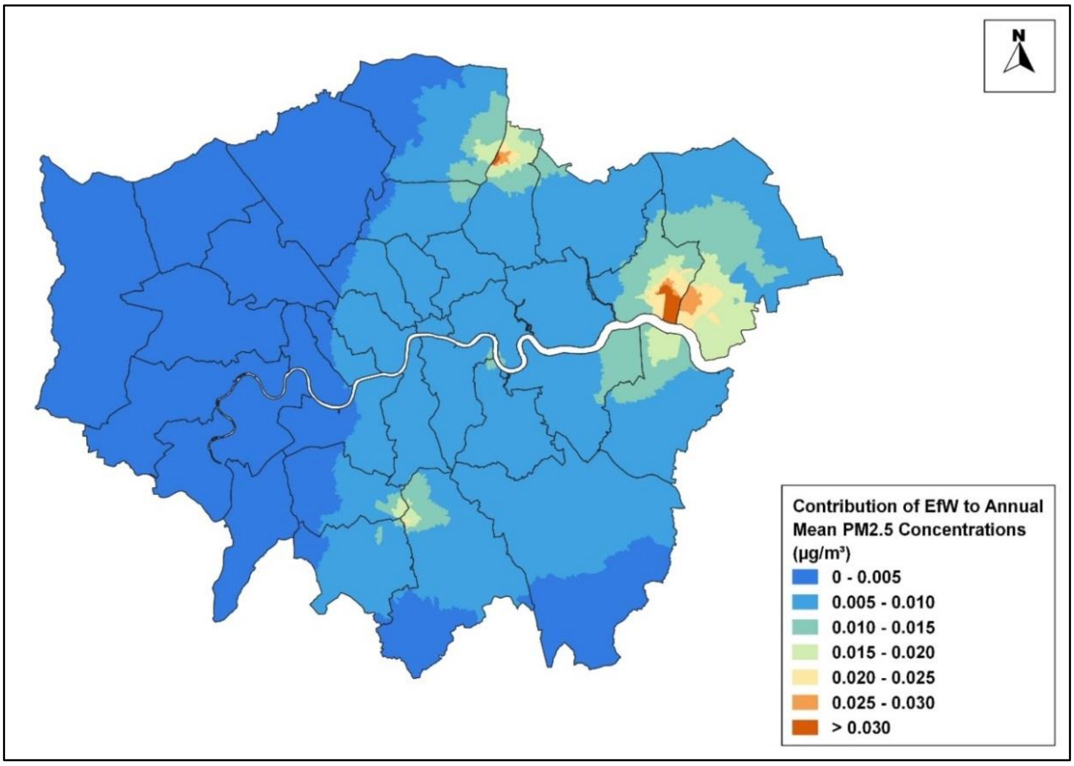

Figure 3: Contribution of Five EfW Facilities to Annual Mean $PM_{2.5}$ Concentrations in each Census Output Area

Population-weighted Concentration Increments

3.32 Figure 4 and Figure 5 show the contributions of the five facilities to population-weighted annual mean concentrations of NO_2 and $PM_{2.5}$ (respectively) in each London borough. These have been calculated by multiplying the concentration increment in each census Output Area by the population of that Output Area. The results have then been summed by borough and divided by the total population in each borough. They show that the population-weighted impacts of within-London EfW plant are not equally distributed; with a clear east-west gradient. Population-weighted concentrations of both NO_2 and $PM_{2.5}$ are highest in Barking and Dagenham and Havering. The lowest population-weighted concentrations are in Hillingdon[7]. The five London boroughs with the highest population-weighted mean NO_2 concentrations (Newham, Greenwich, Bexley, Barking and Dagenham, and Havering – shown as >0.2 $\mu g/m^3$ in Figure 4) are all predicted to experience more than twice the EfW-generated NO_2 concentrations of those in the 11 boroughs shown in shades of blue in Figure 4, i.e. <0.1 $\mu g/m^3$. For the reasons explained in Paragraph 3.31, the distribution is marginally different for $PM_{2.5}$ (Figure 5), but the same general patterns remain.

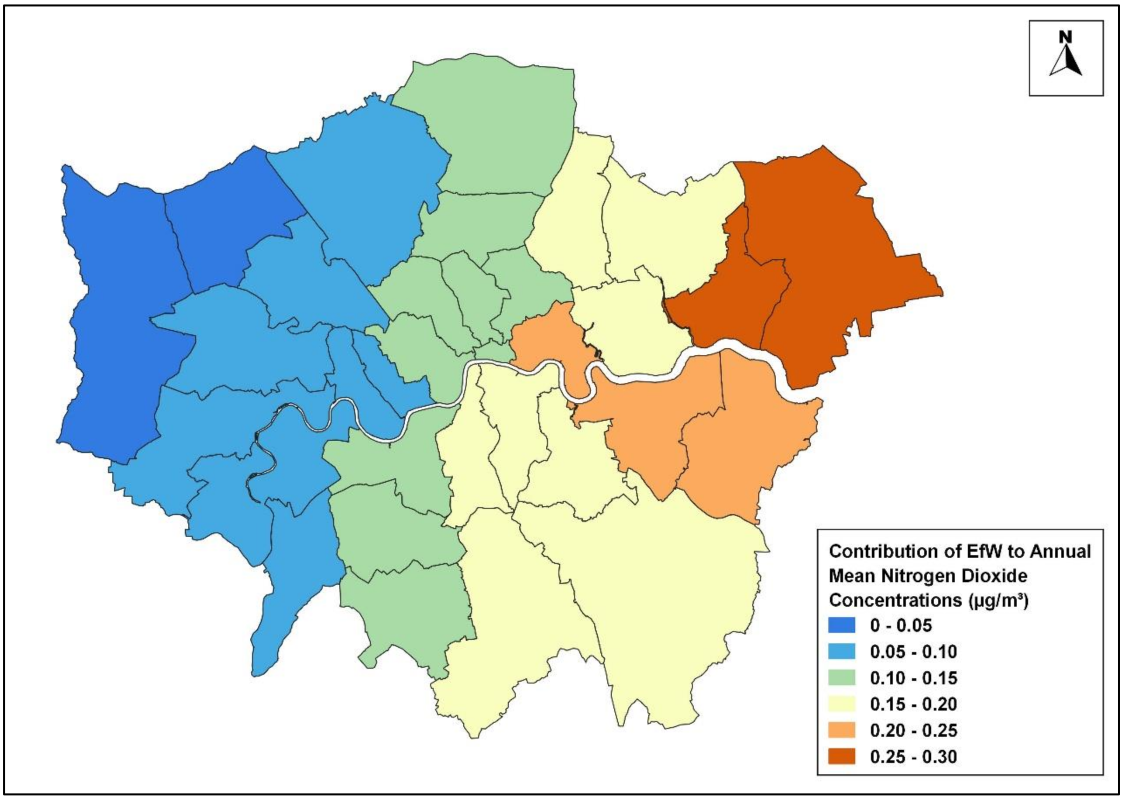

Figure 4: Contribution of Five EfW Facilities to Population-Weighted Annual Mean NO_2 Concentrations in Each London Borough

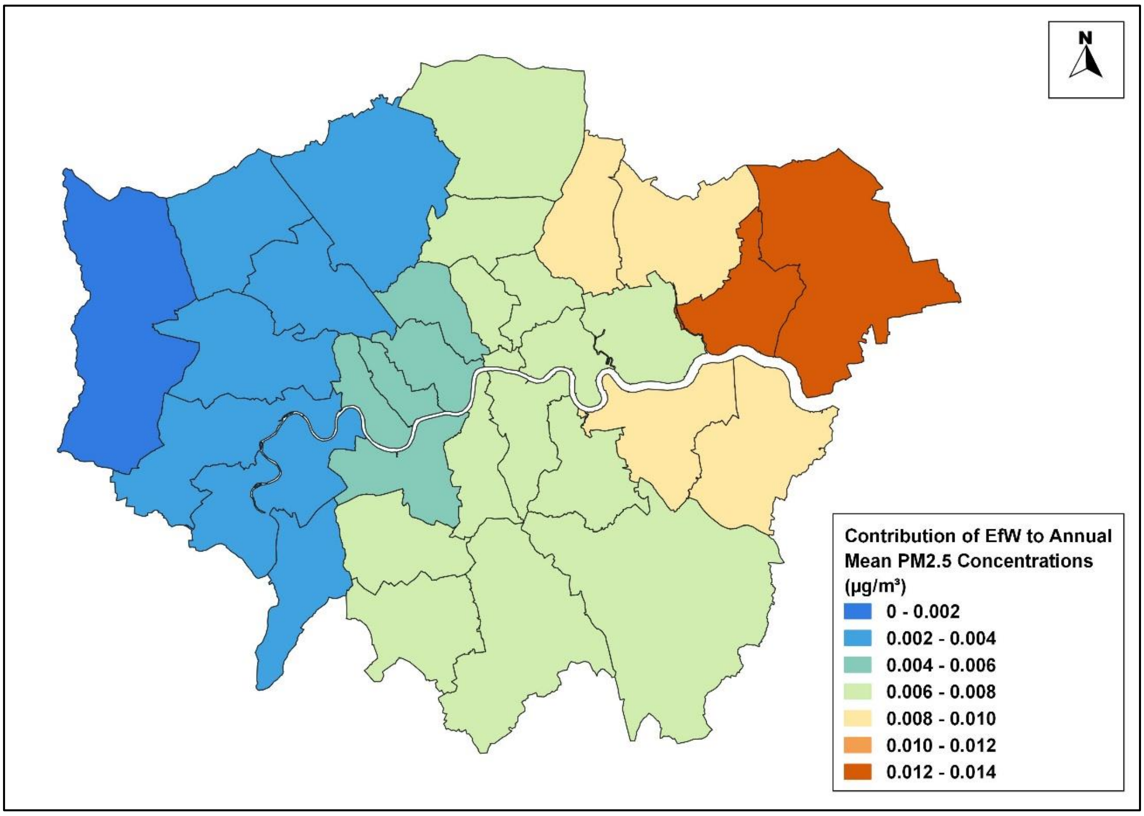

Figure 5: Contribution of Five EfW Facilities to Population-Weighted Annual Mean $PM_{2.5}$ Concentrations in Each London Borough

Health Effects

3.33 Figure 6 summarises the mortality attributed to air pollution from the five EfWs in each London borough. These results, which are expressed per unit population, take account of the population-weighted concentration increments as well as local demographics. As explained in the footnote to the figure, while the values are shown as whole numbers to avoid unnecessary complexity, they are x 10^{-6}, so are 1 million times lower than they might at first appear. The differences in spatial patterns when comparing Figure 4 to Figure 6 is partly an issue of colour-banding, grouping different boroughs together, but also reflects geographical differences in demographics. For example, the total number of non-accidental deaths for people over 30 years old in Havering in 2017 represented approximately 0.92% of the population; which is almost three times the 0.33% recorded in Tower Hamlets. The greatest mortality burden per capita is thus predicted in Havering, with slightly smaller impacts predicted for Bexley and Barking and Dagenham. The smallest mortality burdens are predicted to the west of London.

3.34 Figure 7 and Figure 8 summarise the predicted hospital admissions associated with PM_{10} emissions from the five EfW facilities. These statistics do not take account of borough-specific hospital admissions data and so the spatial pattern shown in each figure is the same and is driven solely by the population-weighted concentration data. In each case, attributable hospital admissions are greatest in Barking and Dagenham, and smallest to the west of London.

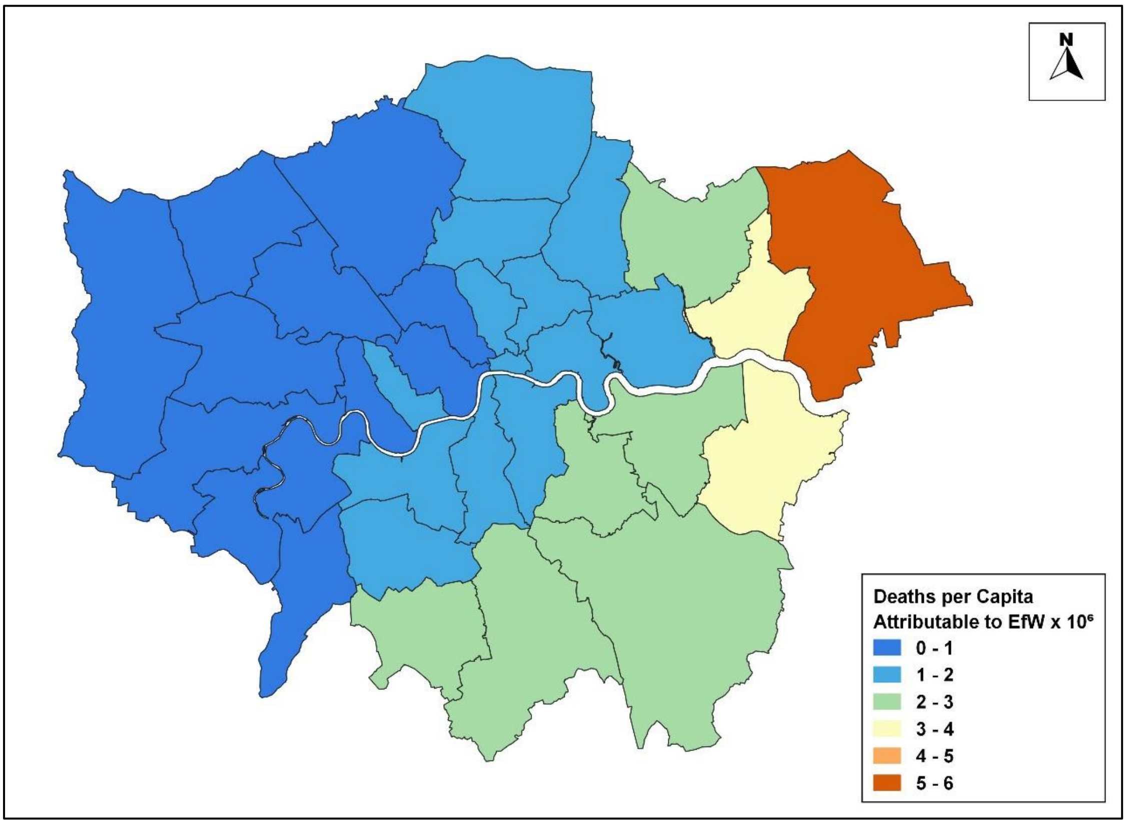

Figure 6: Annual Mortality Attributable to Air Pollution from Five EfW Facilities per Capita by London Borough (deaths brought forward per year)

e.g. 6= 0.000006 deaths brought forward per capita per year.

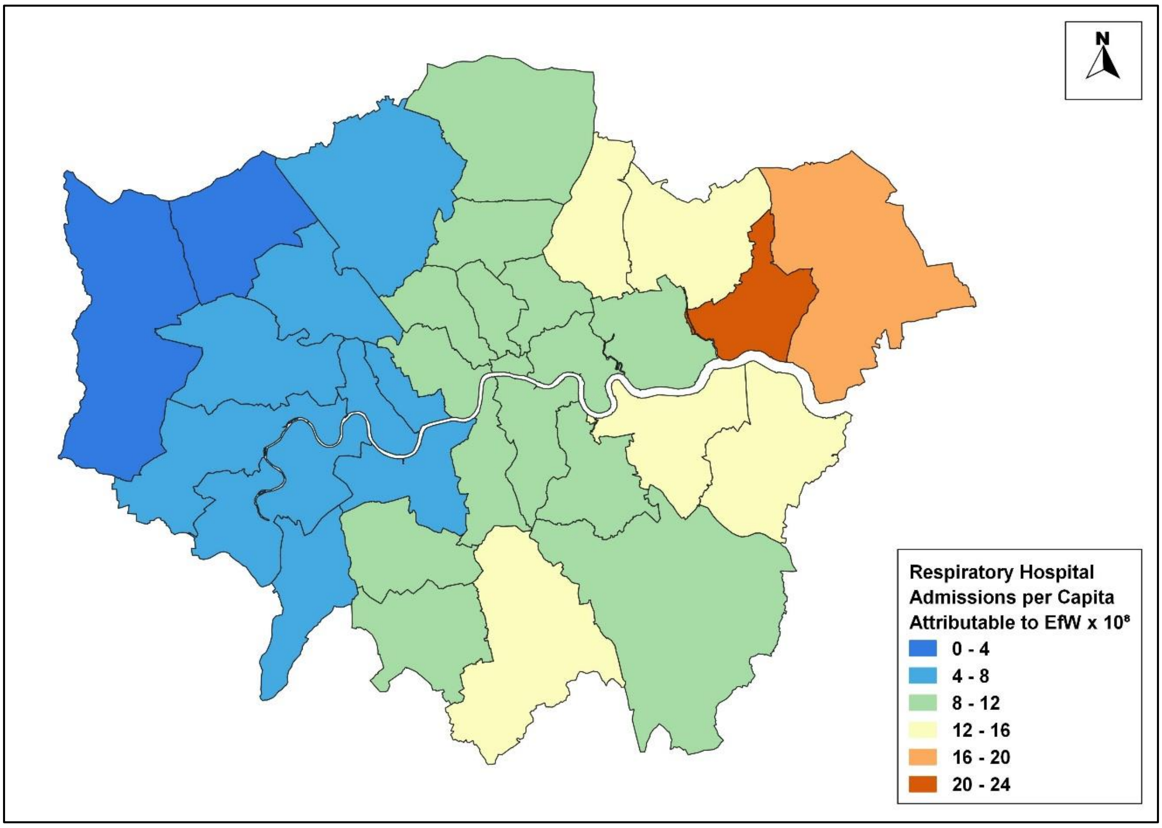

Figure 7: Annual Respiratory Hospital Admissions per Capita Attributable to PM_{10} from Five EfW Facilities by London Borough

e.g. 24 = 0.00000024 admissions per capita per year.

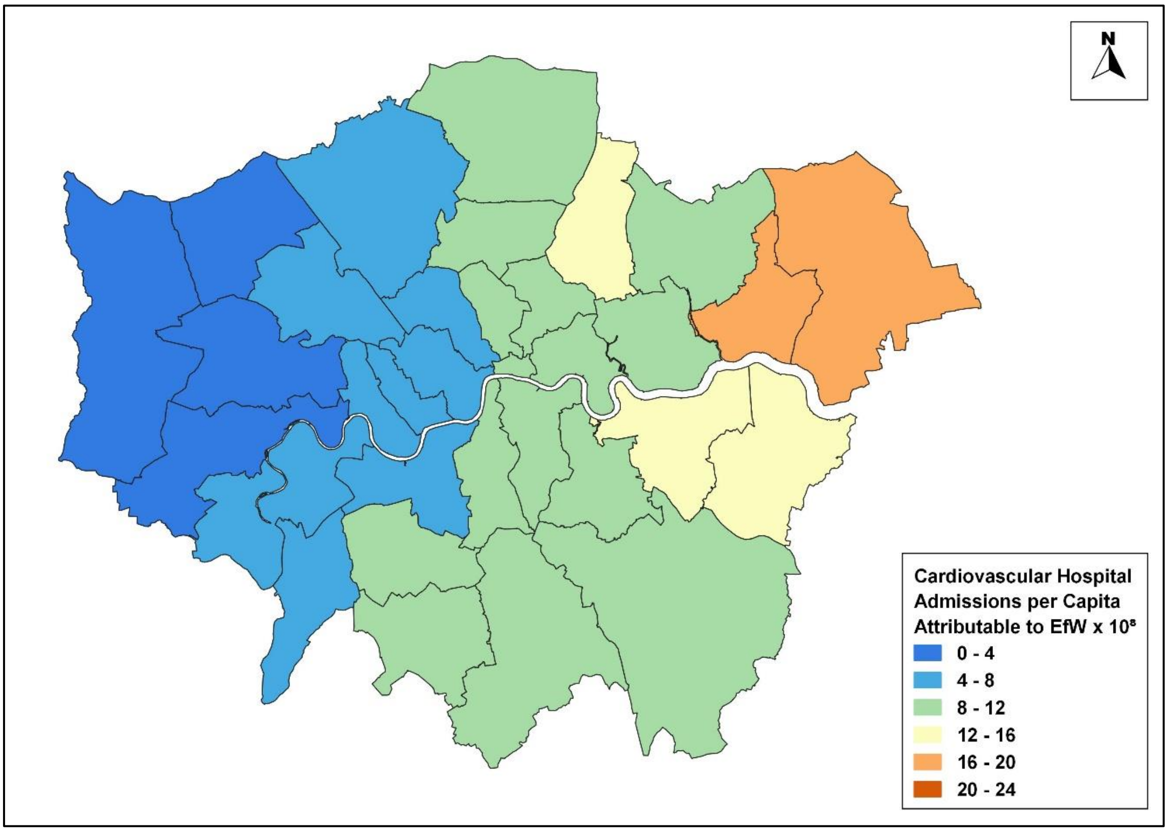

Figure 8: Annual Cardiovascular Hospital Admissions per Capita Attributable to PM_{10} from Five EfW Facilities by London Borough

e.g. 24 = 0.00000024 admissions per capita per year.

Aggregated Health Effects

3.35 The health effects per capita have been summed by the total population in each borough in order to show the total health burden associated with the EfW facilities. 4 summarises the attributable health outcomes across London, with these broken down by borough in 5.

3.36 Over Greater London as a whole, the total burden of mortality from the five EfW facilities has been calculated at 14.7 deaths brought forward per year. This mortality burden is greatest in Havering, with 1.3 deaths brought forward per year,followed by Croydon with 1.0 deaths brought forward per year. This is despite experiencing lower attributable mortality per capita than, for example Newham (see Figure 6), this difference reflecting Croydon's higher total population. Conversely, attributable mortality is lowest in the City of London, reflecting its smaller population.

3.37 The total respiratory hospital admissions attributable to PM_{10} emissions from the five EfW facilities is predicted to be 0.86 admissions per year across the whole of Greater London. The worst affected boroughs are Havering and Croydon, both with 0.047 respiratory admissions per year, followed by Barking and Dagenham with 0.044 admissions.

3.38 The total cardiovascular hospital admissions attributable to PM_{10} emissions from the five facilities is predicted to be 0.76 admissions per year across the whole of Greater London. Again, the greatest number of admissions for any borough is predicted in both Havering and Croydon, followed closely by Barking and Dagenham. The small population of City of London results in it being associated with fewer hospital admissions than areas such as Hammersmith and Fulham, which has lower admissions per capita (see Figure 8), but a greater population.

Table 4: Health Outcomes across the Entire Greater London Urban Area Attributable to Five Energy from Waste Facilities

Area	Mortality Attributable to Air Pollution (total deaths brought forward per year)	Annual Hospital Admissions Attributable to PM_{10}	
		Respiratory Admissions	Cardiovascular Admissions
Greater London	14.65	0.86	0.76

Table 5: Health Outcomes Attributable to Five EfW Facilities by Borough [a]

London Borough	Mortality Attributable to Air Pollution (total deaths brought forward per year)	Annual Hospital Admissions Attributable to PM_{10}	
		Respiratory Admissions	Cardiovascular Admissions
Havering	1.341	0.047	0.041
Croydon	1.010	0.047	0.041
Bexley	0.961	0.036	0.031
Bromley	0.843	0.033	0.029
Greenwich	0.796	0.040	0.035
Barking and Dagenham	0.710	0.044	0.039
Redbridge	0.660	0.041	0.036
Lewisham	0.634	0.033	0.029
Southwark	0.589	0.033	0.029
Newham	0.559	0.040	0.035
Tower Hamlets	0.541	0.035	0.031
Enfield	0.509	0.039	0.034
Lambeth	0.495	0.033	0.029
Waltham Forest	0.490	0.040	0.035
Sutton	0.442	0.019	0.017
Wandsworth	0.379	0.026	0.023
Merton	0.366	0.019	0.017
Hackney	0.331	0.028	0.025
Barnet	0.321	0.021	0.018
Haringey	0.301	0.031	0.027
Islington	0.288	0.024	0.021
Camden	0.262	0.022	0.019
Westminster	0.251	0.021	0.018
Ealing	0.232	0.016	0.014
Brent	0.231	0.017	0.015
Hounslow	0.184	0.012	0.010
Kingston upon Thames	0.183	0.010	0.009
Kensington and Chelsea	0.181	0.012	0.011
Hammersmith and Fulham	0.176	0.013	0.011
Richmond upon Thames	0.165	0.010	0.009
Hillingdon	0.162	0.009	0.008
Harrow	0.139	0.009	0.008
City of London	0.012	0.001	0.001

[a] Ranked by mortality burden

Conclusions

3.39 Emissions from the five EfW facilities within Greater London are predicted to be associated with 15 deaths of London residents per year, as well as 0.9 respiratory hospital admissions and 0.8 cardiovascular hospital admissions per year. There is significant spatial variation within these figures, with a general east-west gradient. For example, the number of deaths brought forward per capita is more than 8 times higher in Havering than in Hillingdon, and more than half of all attributable deaths are predicted to occur within nine boroughs (Havering, Croydon, Bexley, Bromley, Greenwich, Barking and Dagenham, Redbridge, Lewisham, and Southwark). This principally reflects the spatial distribution of the five facilities, but is also influenced by local demographics.

3.40 It is important to recognise that the study only covers the effects within London that are attributable to the five EfW facilities considered, and excludes EfW facilities peripheral to London.

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4 Appendices

A1 Background Monitoring Sites used to Determine NO2:NOx Quotients

Monitoring Site	X	Y
London Eltham AURN	543981	174655
London N. Kensington AURN	524045	181749
London Westminster AURN	529778	178957
London Haringey Priory Park South AURN	529987	188917
London Bloomsbury AURN	530119	182039
London Bexley AURN	551859	176381
Westminster - Covent Garden	530444	180900
Wandsworth - Putney	524035	175516
Wandsworth - Town Hall	525776	174661
Southwark - Elephant and Castle	531893	178844
Richmond Upon Thames - Barnes Wetlands	522991	176730
Redbridge - Ley Street	544454	187679
Lewisham - Catford	537677	173690
Hillingdon - Harlington	508294	177799
Lambeth - Streatham Green	529971	171567
Islington - Arsenal	531328	186033
Harrow - Stanmore	517879	192315
Greenwich - Eltham	543981	174655
Enfield - Prince of Wales School	536885	198504
Enfield - Bush Hill Park	533900	195797
Ealing - Acton Vale	521234	179768
City of London - Sir John Cass School	533482	181187
Bexley - Slade Green	551864	176376
Bexley - Belvedere West	548465	179466
Barking and Dagenham - Scrattons Farm	548046	183320
Barking and Dagenham - Rush Green	551055	187233

A2 Professional Experience

Prof. Duncan Laxen, BSc (Hons) MSc PhD MIEnvSc FIAQM

Prof Laxen is an Associate of Air Quality Consultants, a company which he founded in 1993. He has over 40 years' experience in environmental sciences and has been a member of Defra's Air Quality Expert Group and the Department of Health's Committee on the Medical Effects of Air Pollution. He has been involved in major studies of air quality, including nitrogen dioxide, lead, dust, acid rain, PM_{10}, $PM_{2.5}$ and ozone and was responsible for setting up the UK's urban air quality monitoring network. Prof Laxen has been responsible for appraisals of all local authorities' air quality Review & Assessment reports and for providing guidance and support to local authorities carrying out their local air quality management duties. He has carried out air quality assessments for power stations; road schemes; ports; airports; railways; mineral and landfill sites; and residential/commercial developments. He has also been involved in numerous investigations into industrial emissions; ambient air quality; indoor air quality; nuisance dust and transport emissions. Prof Laxen has prepared specialist reviews on air quality topics and contributed to the development of air quality management in the UK. He has been an expert witness at numerous Public Inquiries, published over 70 scientific papers and given numerous presentations at conferences. He is a Fellow of the Institute of Air Quality Management.

Stephen Moorcroft, BSc (Hons) MSc DIC CEnv MIEnvSc MIAQM

Mr Moorcroft is a Director of Air Quality Consultants, and has worked for the company since 2004. He has over 35 years' postgraduate experience in environmental sciences. Prior to joining Air Quality Consultants, he was the Managing Director of Casella Stanger, with responsibility for a business employing over 100 staff and a turnover of £12 million. He also acted as the Business Director for Air Quality services, with direct responsibility for a number of major Government projects. He has considerable project management experience associated with Environmental Assessments in relation to a variety of development projects, including power stations, incinerators, road developments and airports, with particular experience related to air quality assessment, monitoring and analysis. He has contributed to the development of air quality management in the UK, and has been closely involved with the LAQM process since its inception. He has given expert evidence to numerous public inquiries, and is frequently invited to present to conferences and seminars. He is a Member of the Institute of Air Quality Management.

Dr Ben Marner, BSc (Hons) PhD CSci MIEnvSc MIAQM

Dr Marner is a Technical Director with AQC and has over 20 years' experience in the field of air quality. He has been responsible for air quality and greenhouse gas assessments of road schemes, rail schemes, airports, power stations, waste incinerators, commercial developments and residential developments in the UK and abroad. He has been an expert witness at several public inquiries, where he has presented evidence on health-related air quality impacts, the impacts of air quality on sensitive ecosystems, and greenhouse gas impacts. He has extensive experience of using detailed dispersion models, as well as contributing to the development of modelling best practices. Dr Marner has arranged and overseen air quality monitoring surveys, as well as contributing to Defra guidance on harmonising monitoring methods. He has been responsible for air quality review and assessments on behalf of numerous local authorities. He has also developed methods to predict nitrogen deposition fluxes on behalf of the Environment Agency, provided support and advice to the UK Government's air quality review and assessment helpdesk, Transport Scotland, Transport for London, and numerous local authorities. He is a Member of the Institute of Air Quality Management and a Chartered Scientist. Dr Marner is a member of Defra's Air Quality Expert Group.

Tom Richardson, MSci (Hons)

Mr Richardson is a Consultant with AQC, having joined in April 2018. He has undertaken a number of air quality assessments, including road traffic and energy plant dispersion modelling, construction dust risk assessments, air quality neutral calculations and assessment of impacts on ecological habitats. He currently manages construction dust monitoring at sites across Greater London, and has carried out numerous passive nitrogen dioxide monitoring surveys. He completed an MSci Chemistry at the University of Bristol in 2017, specialising in optical greenhouse gas monitoring methods and data processing using R.

A3 IOM Literature Review

IOM

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Health Impacts associated with Energy-from-Waste Incinerators

Literature Review

Report 144 / August 2019

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Health Health Impacts associated with Energy-from-Waste Incinerators

Customer

Greater London Authority (GLA)

Report Status

Final

Revision

2

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Contents

Executive Summary

The volume of municipal waste going to incinerators in the UK and internationally has substantially increased over the years. Modern municipal solid waste incinerators (MSWIs) are adapted to recover energy from waste and minimise the volume of residues through the incineration process. MSWIs in the UK are currently regulated by EU Directives and operate with the best available technologies to ensure high energy efficiency in the incineration process and low emissions of pollutants to the environment.

This report, commissioned by the Greater London Authority, reviews the recently published (i.e. in the last five years) scientific literature to identify any potential direct impacts of modern MSWIs on human health in the community that would be relevant to London, UK. The literature searches identified 35 relevant studies published in the last 5 years, which have mainly focused on levels of pollutants, such as dioxins and metals, emitted from incinerators, and the assessment of related population exposure and health risks.

The reviewed evidence suggests that well-managed modern MSWIs are unlikely to pose a significant health risk (i.e. cancer, non-cancer, pregnancy, birth and neonatal health) in the UK under the current stringent regulatory regime. Recent epidemiological studies (i.e. population based) have not found consistent evidence of health effects associated with modern MSWIs. However, risk assessment studies (i.e. based on mathematical calculations) have in some cases, mainly in China, estimated cancer risks that exceed recommended ranges. The comparability of the plants included in these studies with modern MSWIs currently operating in the UK is unclear.

Recent epidemiological studies did not find evidence of an association between MSWIs in Great Britain and infant mortality, adverse pregnancy, birth or neonatal outcomes. However, one of these studies found small excess risks associated with congenital heart defects and genital anomalies in proximity to MSWIs. These latest findings may reflect incomplete control for confounding, but a possible causal effect could not be excluded.

Earlier studies did not find convincing evidence of an association of proximity to older incinerators in Great Britain with cancer. Although there is limited evidence of an association of proximity to older incinerators, or exposure to dioxins, with sarcoma and lymphoma risk in other countries, the very substantial decrease in dioxin emissions from MSWIs over recent years is likely to make these risks negligible for populations currently living in the vicinity of modern, well-controlled plants in the UK. It is important to point out that stack emissions from modern MSWIs are much reduced compared to old generation plants.

On the basis of this review, we conclude that any potential health risks associated with direct emissions from modern, effectively managed and regulated MSWIs in London are exceedingly low. However, consideration should be given to secondary pollutant formation (e.g. fine particles formed in the atmosphere from gaseous emissions from MSWIs), as well as to emissions from additional heavy-duty road traffic in the vicinity of the plants.

It is recommended that potential health risks from MSWIs be individually assessed, due to the technical, operational and locational differences between plants. Future epidemiological studies will benefit from exposure assessment methods based on air pollution models, potentially validated through human biomonitoring, clearly defined health outcomes, and robust control of confounding factors (e.g. socioeconomic differences).

Minimising waste generation, maximising recycling and re-use, and limiting incineration to non-recyclable materials, are key priorities for sustainable development. This review did not consider the comparative health risks or benefits of different waste management options or the overall impact of waste incineration on the environment and human health through a combination of direct and indirect mechanisms. Finally, the impact of MSWIs on health inequalities in London was beyond the scope of this review.

Glossary

ATT	Advanced thermal technologies
BSEM	British Society for Ecological Medicine
CO	Carbon monoxide
COPD	Chronic obstructive pulmonary disease
EfW	Energy-from-waste
ELCR	Excess Lifetime Cancer Risk
EU	European Union
HCl	Hydrogen chloride
HI	Hazard index
HPA	Health Protection Agency
ILCR	Incremental Lifetime Cancer Risk
MBT	Mechanical biological treatment
MeHg	Methylmercury
MSWIs	Modern municipal solid waste incinerators
NICE	National Institute for Health and Care Excellence
NLM	National Library of Medicine
NO	Nitrogen monoxide
NO_2	Nitrogen dioxide
NO_x	Nitrogen oxides
PAHs	Polycyclic aromatic hydrocarbons
PCBs	Polychlorinated biphenyls
PCDD/Fs	Polychlorinated dibenzo-p-dioxins/furans
PBDD/Fs	Polybrominated dibenzo-p-dioxins/dibenzofurans
PM	Particulate matter
POPs	Persistent Organic Pollutants
QALYs	Quality-Adjusted Life-Years
SO_2	Sulphur dioxide
VOCs	Volatile Organic Compounds
WID	Waste incineration directive

1. Introduction

Incineration, defined as the controlled burning of waste at high temperatures, eliminates pathogens, reduces the volume of waste and can recover energy from the material (Crowley et al., 2003; Rushton, 2003). Modern municipal solid waste incinerators (MSWIs), also referred to as energy-from-waste (EfW) incinerators, recover energy from municipal waste while reducing landfill growth.

MSWIs are either combustion-based or gasification-based. Combustion-based incinerators add municipal solid waste directly to the combustion chamber and then burn it at high temperature and high oxygen conditions to generate heat and carbon dioxide, as well as incomplete combustion products and solid waste residues (Johnson et al., 2016). Depending on the incineration conditions (i.e. combustion temperature), incomplete combustion products may include organic material (e.g. fly and bottom ash) and inorganic components of the waste such as metals. Metals with lower boiling points (e.g. zinc and cadmium) can be vaporised at lower temperatures, while metals with higher boiling points (e.g. cerium and titanium) are vaporised at very high temperatures (Johnson et al., 2016). Composition of stack emissions depends on waste mix but potentially comprises particulate matter (particles with an aerodynamic diameter smaller than 10 (PM_{10}) and 2.5 ($PM_{2.5}$) micrometres and ultrafine particles), sulphur dioxide (SO_2), nitrogen oxides (NO_x), hydrogen chloride (HCl), carbon monoxide (CO), Volatile Organic Compounds (VOCs), Persistent Organic Pollutants (POPs) such as polychlorinated dibenzo-p-dioxins/furans (PCDD/Fs), polychlorinated biphenyls (PCBs), polybrominated dibenzo-p-dioxins/dibenzofurans (PBDD/Fs), polycyclic aromatic hydrocarbons (PAHs), and heavy metals (e.g. cadmium, thallium, mercury, antimony, arsenic, chromium, cobalt, copper, manganese, nickel, vanadium and lead) (Crowley et al., 2003; Zhang et al., 2016; Douglas et al., 2017).

Gasification-based incinerators use municipal solid waste in a high temperature and low oxygen gasification chamber to generate syngas (a mixture of methane, low molecular weight hydrocarbons, and CO), which can be then combusted to generate heat or used to produce other products (e.g. chemicals, fertilisers, and transportation fuels). Gasification is not commonly used in MSWIs in the UK, but large scale plants have been built and are in operation in Europe, North America and Japan (CIWM, 2019).

The amount of municipal waste going to incinerators in the UK has substantially increased over the years. Two million tonnes of London's municipal waste was sent to MSWIs in 2017; this has more than doubled in the last decade (London Assembly, 2018). The heat generated in these MSWIs can be used for electricity generation or residential heating. London's current EfW facilities combined emit over 2,000 tonnes of NO_x, a combination of nitrogen dioxide (NO_2) and nitrogen monoxide (NO), per year. This is equivalent to 4% of London's overall NO_x emissions. London's EfW facilities also emit 64 tonnes of chlorine, 116 kg of arsenic, and 15 kg of mercury per year (London Assembly, 2018).

Although MSWIs in the UK are tightly regulated through the EU Directive on Industrial Emissions (2010/75/EU), there has been public concern regarding potential health effects associated with atmospheric emissions from these facilities. Modern MSWIs have lower emissions of pollutants than older incinerators that burn unsorted municipal solid waste at lower temperatures. However, it is possible that the increased concentration of certain items (e.g. plastics, textiles, rubber) in sorted waste may lead to higher emissions of carcinogens, including dioxins (such as PCDD/Fs) and chromium, than incinerating unsorted municipal solid waste (Cole-Hunter et al., 2019).

Findings from earlier studies mainly focusing on health effects associated with emissions from older incinerators in different locations have been inconsistent and inconclusive (Porta, 2009; Reeve et al., 2013; Ashworth et al., 2014). A review of the environmental and health effects of waste management in the UK/Europe carried out for Defra (2004) found no consistent evidence for significantly elevated levels of illness in populations potentially affected by emissions from MSWIs. However, the report by the British Society for Ecological Medicine (BSEM) on the health effects of waste incinerators (Thompson and Anthony, 2008) has generated debate on the topic, including responses by the Health Protection Agency (HPA) and Enviros Consulting Ltd.

This present study, commissioned by the Greater London Authority, reviews the recently published (i.e. in the last five years) scientific literature to identify any potential impacts of modern MSWIs on air quality and human health in the general population that would be relevant to London, UK. This review does not cover EfW processes that involve non-combustive heating (gasification) or microorganisms to biologically digest matter (bio-digestion), other municipal waste management options such as landfill, or the disposal of the solid waste from incineration (i.e. ash and filtered emissions).

2. Methods

An overview of the research process is presented in Figure 1.

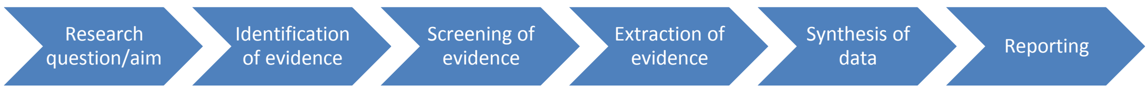


Figure 1 Research Process

2.1. Research question/aim

The aim of this literature review was to establish what, if any, health impacts are associated with proximity to, or exposure to emissions from, Energy from Waste (EfW) plant.

The outcome of the review is an assessment of the strength of evidence of health effects associated with proximity to or emissions from EfW plants, and an assessment of its relevance to such exposures in the UK.

2.2. Identification of evidence

2.2.1. Search strategy

The scope of the study is outlined in **Error! Reference source not found.** below. It was acknowledged hat the information included should be relevant to waste incinerators in London and the technology used.

Table 1 Scope of the study

Population	**Human, individual, population**
Exposure	Proximity, Distance, Spatial variability, Energy and waste, Incineration, Thermal/heat treatment of waste, Municipal solid waste incineration (MSWI), Municipal solid waste (MSW), Waste management, Waste to energy (WTE), Energy from waste (EfW), Mechanical biological treatment (MBT), Advanced thermal technologies (ATT), Emissions, Exposure, Air pollution, Air quality, Particulate matter, PM, PM_{10}, $PM_{2.5}$, Nitrogen dioxide, NO_2, Nitrogen oxides, NO_x, Sulphur dioxide, SO_2,

	Polycyclic Aromatic Hydrocarbons, PAH, Polychlorinated biphenyls, PCB, Heavy metal, Dioxin, Hydrogen chloride, HCl, Carbon monoxide, CO, Volatile Organic Compounds, VOCs, Persistent Organic Pollutants, POPs, Polychlorinated dibenzo-p-dioxins/ furans (PCDD/Fs), Polychlorinated biphenyls (PCBs), Mercury, Furans, Phthalates, Ketones, Aldehydes, Organic acids, Alkenes, Ultrafine particles, Organochlorines, Fly ash
Health outcomes	Disease, Illness, Mortality (all cause), Respiratory mortality, Respiratory morbidity, Inflammatory response, Asthma, Exacerbations, Symptoms, Chronic Obstructive Pulmonary Disease (COPD), Cardiovascular mortality, Cardiovascular morbidity, Cardiac symptoms, Cardiac parameters, Cancer, Mental health, Cognition, Dementia, Diabetes, Prenatal effects, Birth weight, Intrauterine growth, Hospital admissions, Primary care visits, GP visits, Disability-adjusted life-years, Quality-Adjusted Life-Years (QALYs)
Types of Studies	Systematic reviews, Reviews, Observational studies, Modelling studies, Exposure assessment
Inclusion Criteria	Papers published in the last 5 years; In English language; UK and International evidence; Scientific literature; Grey literature
Exclusion Criteria	Papers published more than 5 years ago; Papers not in English; Studies not related to Energy from Waste incineration; Studies not related to Municipal Solid Waste; Occupational exposure studies; Studies relating to radioactive or clinical waste; Life Cycle Analysis (LCA) studies

2.2.2. Search strategy for publication databases

The search terms included in the above table were reviewed by Air Quality Consultants who advised on this review. Following this the search terms were then translated into search strings for literature searches.

Following preliminary trial searches in Web of Science the following search string was developed and run in Web of Science Core Collection, NLM PubMed and Google Scholar with the restriction for the last five years:

> incinerat* OR (waste AND energy) AND (exposure OR emission* OR pollut* OR proximity OR distance) AND (disease OR illness OR respiratory OR lung OR breath* OR cardiovascular OR cancer OR "mental health" OR dementia OR diabetes)

A supplementary search string specifically to identify literature pertaining to birth defects in relation to MSWI was run in Web of Science Core Collection and Google Scholar:

> incinerat* OR (waste AND energy) AND (exposure OR emission* OR pollut* OR proximity OR distance) AND (reproduct* OR miscarriage OR "birth defect" OR "birth outcome")

Additional papers were identified by Air Quality Consultants: the British Society for Ecological Medicine report on the health effects of waste incinerators (Thompson and Anthony, 2008) and subsequent responses by the Health Protection Agency and Enviros. These publications were outside our inclusion period, but their findings are discussed in the context of the findings of the more recent studies included in this review.

We also used "snowballing" (i.e. checking of the references sections of articles that have been included in the review) to identify additional relevant studies.

2.3. Screening of evidence

The bibliographic information of the evidence identified was saved in the reference management software RefWorks; this included abstracts (where available).

The full references and abstracts were extracted into an Excel spreadsheet for the initial stage of screening. Using the inclusion and exclusion criteria, the papers were screened independently by two reviewers on the basis of their title and abstract (where available) to identify studies of relevance. Inappropriate titles/abstracts were filtered out of the list of publications identified for full-text scanning. In all cases a conservative strategy was adopted where, if the relevance or otherwise of a paper was not apparent from the title and/or abstract, the paper was retained for full text scanning and possible review. A random sample of 10% of papers was independently checked by a third reviewer and the results compared for quality assurance purposes. Any discrepancies were resolved by discussion among the three reviewers.

2.4. Extraction of evidence

The references included as a result of the initial screening of titles and abstracts were sourced to obtain full texts for the extraction of evidence.

To ensure a systematic and consistent approach to information extraction an Excel template was developed. The fields that were assessed and populated are set out in Table 2.

Table 2 Data extraction fields

Data extraction categories	Data extraction fields
Paper/reference information	• RefWorks ID number • Reference
Reviewer	• Reviewer initials
1st screening (relevant types of incinerator)	• Does the paper deal with 'municipal waste only' and/or 'energy from waste' (yes/no and state type) • 1st screening result (include/exclude based on type of incinerator)

2nd screening (relevance to London incinerators)	• Emissions/concentrations of pollutants • Annual licensed throughput of waste • Number of flues at incinerator • Whether the incinerator opened to or adopted EU-WID (waste incineration directive) specifications • Height and diameter of the incinerator stack (m) • Exit temperature (°C) and exit velocity (m s^{-1}) per flue • 2nd screening result (include-relevant/exclude-not relevant based on applicability to London incinerators)
Study details	• What research question(s) does the study address? • Study design (e.g. epidemiological, risk assessment) • Country/City • Year
Plant details	• Age of plant
Health effects	• Health effects covered
Emissions/pollutants	• Emissions/pollutants covered
Exposure metrics	• Proximity covered by study • Modelled/measured exposure levels
Summary of relevant results/how helps to answer research question	• Research question - Literature review to establish what, if any, health impacts are associated with proximity to, or exposure to emissions from, energy from waste plant
Quality assessment summary	• Are the study results internally valid (i.e. unbiased)? • Are the findings generalisable to the source population (i.e. externally valid)?
Additional information	• Any evidence gaps identified or any additional notes and comments

The data extraction criteria '1st screening (relevant types of incinerator)' (see Table 2) allowed us to check the type of incinerator (municipal solid waste and/or energy-from-waste). If the paper was not concerned with municipal solid waste or EfW then it was excluded and no further data was extracted. Where the type of incinerator was included then we assessed the criteria of '2nd screening (relevance to London incinerators)' (see Table 2) to ensure the incinerator was of relevance to London. If the incinerator was not relevant to London then the paper was excluded and no further data was extracted.

The data extraction template was trialled by the IOM project team before being reviewed by Air Quality Consultants and agreed for use.

The data extraction was completed by one topic expert and a 10% sample checked by a second reviewer; with any discrepancies being discussed with a third reviewer.

2.5. Synthesis of data

2.5.1. Quality of the evidence

To identify the 'Quality assessment summary' in Table 2 above we used an adapted version of the NICE public health guidance Quality Appraisal Checklist for quantitative intervention studies (NICE, 2012)[1]. The checklist is designed to:

> *"appraise a study's internal and external validity after addressing the following key aspects of study design:*
> - *characteristics of study participants*
> - *definition of, and allocation to, intervention and control conditions*
> - *outcomes assessed over different time periods*
> - *methods of analyses."*

The 'quality assessment summary' was scored using '++', '+' or '−' and recorded in the data extraction spreadsheet.

++ For that aspect of study design, the study has been designed or conducted to minimise the risk of bias.

\+ Either the answer to the checklist question is not clear from the way the study is reported, or the study may not have addressed all potential sources of bias for that particular aspect of study design.

− For aspects of the study design in which significant sources of bias may persist.

To reach the 'quality assessment summary' score the reviewer was guided by the items in Table 3 below.

Table 3 Quality Assessment Criteria

Quality assessment section	Quality assessment criteria
Quality Assessment Section 1: Population/Setting (Yes/Can't tell/No)	1.1 Is the exposed population or source area well described? 1.2 Do the selected participants or areas represent the eligible population or area? Did the setting reflect usual UK practice?
Quality Assessment Section 2: Study methods (Yes/Can't tell/No)	2.1 Does the study address a clearly focused issue? 2.2 Were the study design and statistical methods appropriate?

[1] NICE (National Institute for Health and Care Excellence). (2012). Methods for the development of NICE public health guidance (3rd Edition). London: NICE. PMG4).

	2.3 Were all important confounding factors taken into account? 2.4 If a cohort study, was the follow-up of subjects complete/long enough?
Quality Assessment Section3: Exposure Assessment (Yes/Can't tell/No)	3.1 Was the exposure accurately measured to minimise bias? 3.2 Were the substances measured relevant? 3.3 Was data provided on the precision of the measurements? 3.4 Were levels below limit of detection dealt with adequately?
Quality Assessment Section 4: Health Outcomes (Yes/Can't tell/No)	4.1 Were outcome measures reliable? 4.2 Were all outcome measurements complete? 4.3 Were all important outcomes assessed? 4.4 Were all measured outcomes relevant?
Quality Assessment Section 5: Summary (++/+/-)	5.1 Are the study results internally valid (i.e. unbiased)? 5.2 Are the findings generalisable to the exposed population (i.e. externally valid)?
Additional information	Any evidence gaps identified or any additional notes and comments

The quality assessment criteria were trialled by the IOM project team and agreed with Air Quality Consultants before use.

3. Results

There are relatively few research studies of modern MSWIs operating to current EU Industrial Emissions Directive standards. From the screened papers, we retained 35 eligible studies for data extraction in our review, including 6 literature reviews, as summarised in Table 4. Three of the included studies are related to UK based MSWIs, while 9 exposure/risk assessment studies come from China where the use of waste incineration is increasing rapidly.

Table 4 Studies included

Study type / country	Reference*
Systematic review / Worldwide	Ashworth DC, Elliott P, Toledano MB. (2014). Waste incineration and adverse birth and neonatal outcomes: a systematic review. Environment International; 69: 120-132.
Epidemiological study / Italy	Candela S, Bonvicini L, Ranzi A, Baldacchini F, Broccoli S, Cordioli M; Carretta E, Luberto F, Angelini P, Evangelista A, Marzaroli P, Rossi PG, Forastiere F. (2015). Exposure to emissions from municipal solid waste incinerators and miscarriages: A multisite study of the MONITER Project. Environment International; 78: 51-60.
Case-control / China	Deng C, Xie H, Ye X, Zhang H, Liu M, Tong Y, Ou L, Yuan W, Zhang W, Wang X. (2016). Mercury risk assessment combining internal and external exposure methods for a population living near a municipal solid waste incinerator. Environmental Pollution; 219: 1060-1068.
Exposure and risk assessment / Spain	Domingo JL, Rovira J, Nadal M, Schuhmacher M. (2017). High cancer risks by exposure to PCDD/Fs in the neighborhood of an Integrated Waste Management Facility. Science of the Total Environment; 607: 63-68.
Exposure and risk assessment / Spain	Domingo JL, Rovira J, Vilavert L, Nadal M, Figueras MJ, Schuhmacher M. (2015). Health risks for the population living in the vicinity of an Integrated Waste Management Facility: screening environmental pollutants. Science of the Total Environment; 518–519: 363–370.
Dispersion modelling / Great Britain	Douglas P, Freni-Sterrantino A, Sanchez ML, Ashworth DC, Ghosh RE, Fecht D, Font A, Blangiardo M, Gulliver J, Toledano MB, Elliott P, de Hoogh K, Fuller GW, Hansell AL. (2017). Estimating Particulate Exposure from Modern

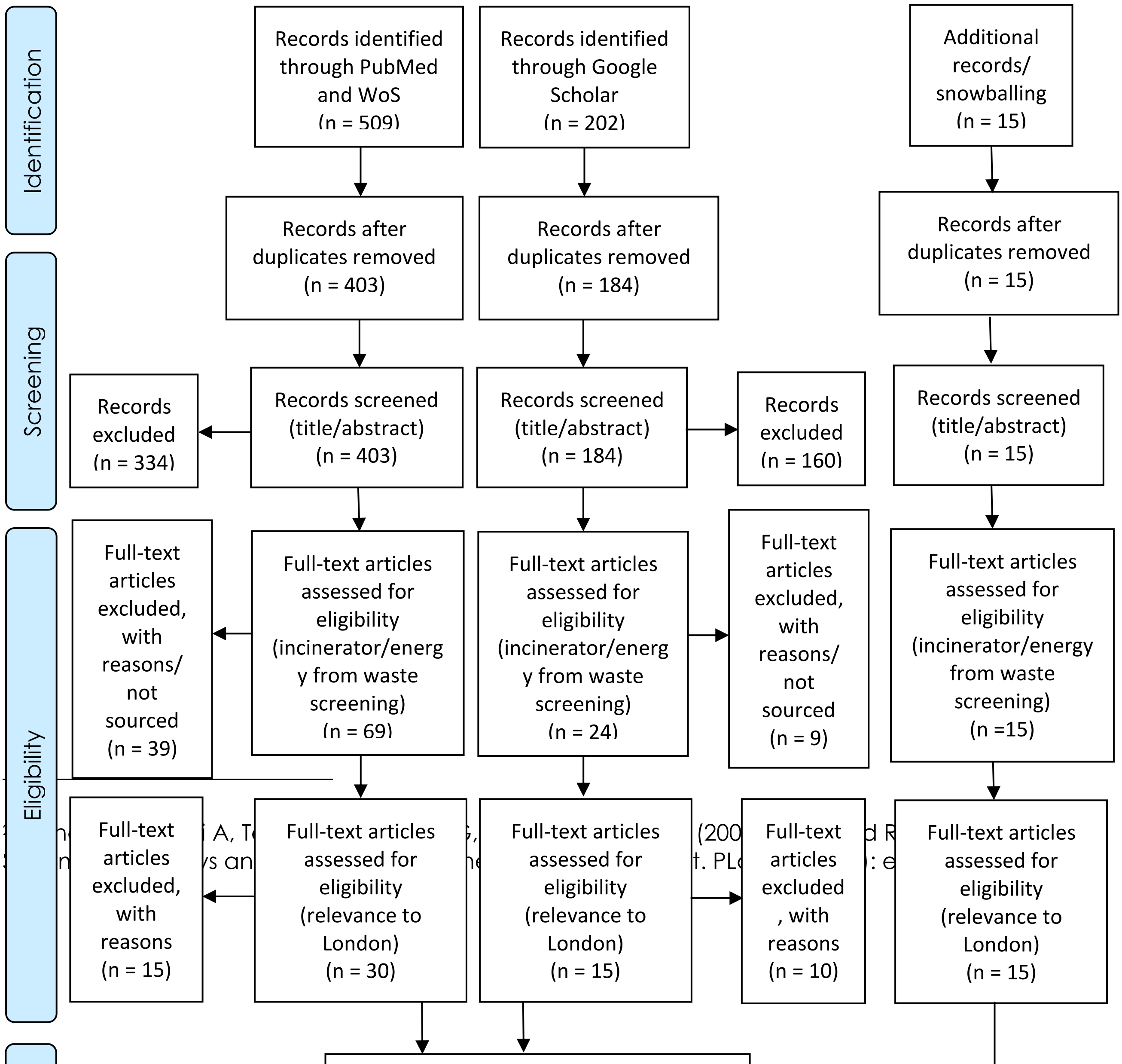
	Municipal Waste Incinerators in Great Britain. Environmental Science & Technology; 51: 7511-7519.
Interrupted time series / England and Wales	Freni-Sterrantino A., Ghosh R.E., Fecht D., Toledano M.B., Elliott P., Hansell A.L., Blangiardo M. (2019). Bayesian spatial modelling for quasi-experimental designs: An interrupted time series study of the opening of Municipal Waste Incinerators in relation to infant mortality and sex ratio. Environment International; 128: 109–115.
Case-control / Great Britain	Ghosh R.E., Freni-Sterrantino A., Douglas P., Parkes B., Fecht D., de Hoogh K., Fuller G., Gulliver J., Font A., Smith R.B., Blangiardo M., Elliott P., Toledano M.B., Hansell A.L. (2019). Fetal growth, stillbirth, infant mortality and other birth outcomes near UK municipal waste incinerators; retrospective population based cohort and case-control study. Environment International; 122: 151–158.
Case studies / USA	Ghosh SK, Lee J, Godwin AC, Oke A, Al-Rawi R, El-Hoz M. (2016). Waste management in USA through case studies: e-waste recycling and waste energy plant. In Proceedings of the 31st international conference on solid waste technology and management, 3-6 April 2016, Philadelphia, USA. Pennsylvania: Widener University.
Exposure and risk assessment / Taiwan	Ho C, Chan C, Chio C, Lai Y, Chang-Chien G, Chow JC, Watson JG, Chen LA, Chen P, Wu C. (2016). Source apportionment of mass concentration and inhalation risk with long-term ambient PCDD/Fs measurements in an urban area. Journal of Hazardous Materials; 317: 180-187.
Sample analysis and risk assessment / China	Jia J, Bi C, Guo X, Wang X, Zhou X, Chen Z. (2017). Characteristics, identification, and potential risk of polycyclic aromatic hydrocarbons in road dusts and agricultural soils from industrial sites in Shanghai, China. Environmental Science and Pollution Research; 24: 605-615.
Literature review / Worldwide	Johnson DR. (2016). Nanometer-sized emissions from municipal waste incinerators: A qualitative risk assessment. Journal of Hazardous Materials; 320: 67-79.
Literature review / Italy and Scandinavia	Jones AM, Harrison RM. (2016). Emission of ultrafine particles from the incineration of municipal solid waste: A review. Atmospheric Environment; 140: 519-528.
Case-control / France	Kalfa N, Paris F, Philibert P, Orsini M, Broussous S, Fauconnet-Servant N, Audran F, Gaspari L, Lehors H, Haddad M, Guys JM, Reynaud R, Alessandrini P, Merrot T, Wagner K, Kurzenne JY, Bastiani F, Breaud J, Valla JS, Lacombe GM, Dobremez E, Zahhaf A, Daures JP, Sultan C. (2015). Is Hypospadias Associated with Prenatal Exposure to Endocrine Disruptors? A French collaborative controlled study of a cohort of 300 consecutive children without

	genetic defect. European Urology; 68(6): 1023-1030.
Exposure and risk assessment / China	Li J, Dong H, Sun J, Nie J, Zhang S, Tang J, Chen Z. (2016). Composition profiles and health risk of PCDD/F in outdoor air and fly ash from municipal solid waste incineration and adjacent villages in East China. Science of the Total Environment; 571: 876-882.
Exposure and risk assessment / China	Li J, Zhang Y, Sun T, Hao H, Wu H, Wang L, Chen Y, Xing L, Niu Z. (2018). The health risk levels of different age groups of residents living in the vicinity of municipal solid waste incinerator posed by PCDD/Fs in atmosphere and soil. Science of the Total Environment; 631-632: 81-91.
Exposure and risk assessment / China	Li N, Kang Y, Pan W, Zeng L, Zhang Q, Luo J. (2015). Concentration and transportation of heavy metals in vegetables and risk assessment of human exposure to bioaccessible heavy metals in soil near a waste-incinerator site, South China. Science of the Total Environment; 521: 144-151.
Exposure and risk assessment / China	Ma W, Tai L, Qiao Z, Zhong L, Wang Z, Fu K, Chen G. (2018). Contamination source apportionment and health risk assessment of heavy metals in soil around municipal solid waste incinerator: A case study in North China. Science of the Total Environment; 631: 348-357.
Exposure assessment / China	Meng N., Ma W-L., Liu L-Y., Zhu N-Z., Song W-W., Lo C.Y., Li J., Kannan K., Li Y-F. (2016). PCDD/Fs in soil and air and their possible sources in the vicinity of municipal solid waste incinerators in northeastern China. Atmospheric Pollution Research 7 (2), 355-362.
Literature review / Worldwide	Ncube F, Ncube EJ, Voyi K. (2017). A systematic critical review of epidemiological studies on public health concerns of municipal solid waste handling. Perspectives in Public Health; 137: 102-108.
Literature review / Worldwide	Nicoll R. (2018). Environmental contaminants and congenital heart defects: a re-evaluation of the evidence. International Journal of Environmental Research and Public Health; 15(10): 2096.
Epidemiological study / England and Scotland	Parkes B, Hansell AL, Ghosh RE, Douglas P, Fecht D, Wellesley D, Kurinczuk JJ, Rankin J, de Hoogh K, Fuller GW, Elliott P. (2019). Risk of congenital anomalies near municipal waste incinerators in England and Scotland: Retrospective population-based cohort study. Environment International (in press).
Exposure and risk assessment / Spain	Rovira J., Nadal M., Schuhmacher M., Domingo J.L. (2018). Concentrations of trace elements and PCDD/Fs around a municipal solid waste incinerator in Girona (Catalonia,

	Spain). Human health risks for the population living in the neighbourhood. Sci Total Environ; 630: 34-45.
Epidemiological study / Italy	Santoro, M; Minichilli, F; Linzalone, N; Coi, A; Maurello, MT; Sallese, D; Bianchi, F (2016) Adverse reproductive outcomes associated with exposure to a municipal solid waste incinerator. Annali Dell Istituto Superiore Di Sanita; 52(4): 576-581.
Dispersion modelling	Scungio M, Buonanno G, Arpino F, Ficco G. (2015). Influential parameters on ultrafine particle concentration downwind at waste-to-energy plants. Waste Management; 38: 157-163.
Exposure and risk assessment / Italy	Scungio M, Buonanno G, Stabile L, Ficco G. (2016). Lung cancer risk assessment at receptor site of a waste-to-energy plant. Waste Management; 56: 207-215.
Exposure study / Switzerland	Setyan A, Patrick M, Wang J. (2017). Very low emissions of airborne particulate pollutants measured from two municipal solid waste incineration plants in Switzerland. Atmospheric Environment; 166: 99-109.
Dietary intake and risk assessment / China	Shen H, Guan R, Ding G, Chen Q, Lou X, Chen Z, Zhang L, Xing M, Han J, Wu Y. (2017). Polychlorinated dibenzo-p-dioxins/furans (PCDD/Fs) and polychlorinated biphenyls (PCBs) in Zhejiang foods (2006-2015): Market basket and polluted areas. Science of the Total Environment; 574: 120-127.
Exposure and risk assessment / Spain	Vilavert L, Nadal M, Schuhmacher M, Domingo JL. (2015). Two decades of environmental surveillance in the vicinity of a waste incinerator: human health risks associated with metals and PCDD/Fs. Arch. Environ. Contam. Toxicol.; 69: 241-253.
Case-control / Italy	Vinceti M, Malagoli C, Werler MM, Filippini T, De Girolamo G, Ghermandi G, Fabbi S, Astolfi G, Teggi S. (2018). Adverse pregnancy outcomes in women with changing patterns of exposure to the emissions of a municipal waste incinerator. Environmental Research; 164: 444-451.
Literature review / Worldwide	Wielgosiński G, Targaszewska A. (2014). The impact of waste incineration on human beings and the environment. Ecological Chemistry and Engineering S; 21: 353-363.
Exposure study / Taiwan	Yang H, Luo S, Lee K, Wu J, Chang CW, Chu PF. (2016). Fine particulate speciation profile and emission factor of municipal solid waste incinerator established by dilution sampling method. Journal of the Air & Waste Management Association; 66: 807-814.
Literature review / Worldwide	Zhang MM, Buekens A, Li XD. (2016). Brominated flame retardants and the formation of dioxins and furans in fires

	and combustion. Journal of Hazardous Materials; 304: 26–39.
Exposure assessment / China	Zhou Z, Ren Y, Chu J, Li N, Zhen S, Zhao H, Fan S, Zhang H, Xu P, Qi L. (2016). Occurrence and impact of polychlorinated dibenzo-p-dioxins/dibenzofurans in the air and soil around a municipal solid waste incinerator. J. Environ. Sci.; 44: 244-251.
Exposure of prospective cohort / Spain	Zubero MB, Eguiraun E, Aurrekoetxea JJ, Lertxundi A, Abad E, Parera J, Goñi-Irigoyen F, Ibarluzea J. (2017). Changes in serum dioxin and PCB levels in residents around a municipal waste incinerator in Bilbao, Spain. Environ Res.; 156: 738-746.

*References in alphabetic order by first author's surname
A copy of the data extraction spreadsheet for the included papers is provided alongside this document. In Figure 2 a PRISMA diagram[2] presents the numbers of papers identified, screened and assessed for eligibility at each stage (provisional numbers inserted). The main findings from these papers are summarised in sections 3.1-3.3.



3.1. Cancer

We found two literature reviews (Ncube et al. 2017; Wielgosiński and Targaszewska, 2014) and five original research papers from Spain (Vilavert et al., 2015; Zubero et al., 2017; Domingo et al., 2015; 2017; Rovira et al., 2018), published in the last 5 years, that examine cancer risk in relation to distance from or exposure to emissions from MSWIs. We also used "snowballing" to identify and briefly discuss a number of earlier studies on cancer effects.

Ncube et al. (2017) systematically reviewed the epidemiological literature on health effects of municipal solid waste handling, including landfill and incineration published in the period 1995–2014. They found limited evidence linking incinerators in Italy with sarcoma and lymphoma risk (Zambon et al. 2007; Biggeri and Catelan, 2005). Zambon et al. (2007) examined cases of sarcoma diagnosed between 1990 and 1996 in northern Italy and found an association between modelled dioxin exposure and sarcoma risk. Biggeri and Catelan (2005) found increased risk of all lymphomas over the period 1986-1992 in an area affected by dioxin in soil contaminated by an urban waste incinerator which operated from 1973 to 1986. They also observed two deaths from soft tissue sarcoma over the same period. Overall, the evidence presented in the studies reviewed by Ncube et al. (2017) corresponds to older incinerators in Italy and is not considered to be relevant to the modern MSWIs currently operating in the London area which are compliant with the EU Directive on Industrial Emissions.

Wielgosiński and Targaszewska (2014) reviewed the chemical hazards associated with waste incineration plants and their health consequences. They focused on the health effects of dioxins (PCDD/Fs) for residents in areas affected by waste incineration plants built in the 1970s, 1980s and 1990s, as reported in studies from Belgium (Nouwen et al. 2001), France (Fabre et al. 2007; Floret et al. 2003), Portugal (Fátima-Reis et at. 2007), and Italy (Zambon et al. 2007). Although not conclusive, findings from these studies show an association between several cancers (e.g. sarcoma, non-Hodgkin's lymphoma) and exposure to dioxins or proximity to older waste incinerators. However, dioxin levels in air or soil were not generally monitored as part of these studies, therefore exposures were only estimated approximately.

An earlier large study that investigated cancer incidence in people living near MSWIs in Great Britain between 1974 and 1987 (Elliot et al. 1996; 2000) found statistically significant decline in risk for all cancers with distance, including stomach, colorectal, liver and lung cancers. However, there was evidence of residual socio-economic confounding near the incinerators, which seemed to be a likely explanation of the findings for all cancers, stomach and lung, and also to explain at least part of the excess of liver cancer. On the basis of these findings, the UK Committee on Carcinogenicity of Chemicals in Food, Consumer Products and the Environment suggested that any potential risk of cancer due to residency (for periods in excess of 10 years) near to MSWIs was exceedingly low and probably not measurable by modern epidemiological techniques (COC, 2000). However, the Committee commented that the finding of two cases of angiosarcoma (in the histopathology review by Elliot et al. 2000) in individuals who were resident within 7.5 km of a MSWI was unexpected, but agreed that there was no evidence more generally of clustering near incinerators of cases of angiosarcoma in a national register (COC, 2000).

Other earlier studies undertaken in other countries have reported excess risks for hematologic cancers, lung cancer, and some cancers of the digestive system (Biggeri et al., 1996; Floret et al., 2003; Knox, 2000; Ranzi et al., 2011; Viel et al., 2011). A large study on cancer mortality from Spain (Garcia-Perez et al., 2013) found a statistically significant increase in the risk of dying from cancer in towns near MSWIs and installations for the recovery or disposal of hazardous waste. In the Garcia-Perez et al. (2013) study, population exposure to pollution was estimated by taking the distance from the centroid of the town of residence to the plants, which included incinerators of solid municipal and special (hazardous) waste (nine pre-2002 and five pre-1993 installations). The results showed excess risks for all cancers combined and for lung cancer, and in particular, marked increases in risk of tumours of the pleura and gallbladder (men) and stomach (women) with proximity to incinerators. Individual analyses of the installations revealed statistically significant associations with non-Hodgkin's lymphoma in the vicinity of two MSWIs situated in the same town, as well as high excess risks of tumours of the ovary and brain in women living in the vicinity of another MSWI.

A more recent study in northern Spain (Zubero et al., 2017) did not find higher blood levels of organochlorines (including PCDD/Fs and polychlorinated biphenyls (PCBs)) in individuals living near a MSWI that started operating in 2005 compared to those living further afield. Furthermore, the intake of local food produced near the MSWI was not associated with an increase in the blood concentration of the organochlorines analysed. They also found a very significant decrease in blood concentrations of all studied pollutants by 2013 compared to 2006. These findings are in agreement with those reported by Ranzi et al. (2011), who found that the ratio of emissions in 2008 to those in 1994-1996 for two Italian incinerators was about 0.0001 for dioxins and furans. Other studies analysing trends over time in areas close to MSWIs made similar observations, with no increase in levels of organochlorines in the vicinity of MSWIs (Deml et al., 1996; Evans et al., 2000; González et al., 2000; Chen et al., 2004; Huang et al., 2007; Reis et al., 2007; De Felip et al., 2008; Parera et al., 2013).

However, Domingo et al (2015; 2017) observed persistently high levels of PCDD/Fs in air and soil in the vicinity of an old large MSWI in Catalonia, Spain, after installation of a new gas cleaning system, with associated lifetime cancer risk estimates for local residents exceeding one per million. PCDD/Fs levels and associated cancer risks were much lower in the vicinity of other MSWIs in Catalonia (Vilavert et al., 2015; Rovira et al., 2018), which highlights the importance of assessing the cancer risks around incinerators on case-by-case basis.

3.2. Adverse pregnancy, birth and neonatal outcomes

We found three literature reviews (Ashworth et al. 2014; Ncube et al. 2017, Nicoll, 2018), three studies from the UK (Freni-Sterrantino et al. 2019; Ghosh et al. 2019; Parkes et al., 2019), three studies from Italy (Candela et al. 2015; Vinceti et al. 2018, Santoro et al, 2016) and one study from France (Kalfa et al. 2015), published within the last five years, which have examined adverse pregnancy, birth and neonatal outcomes in association with waste incineration.

Ashworth et al. (2014) conducted a systematic review of epidemiologic studies evaluating the relationship between waste incineration and the risk of adverse birth and neonatal outcomes. They identified 14 studies (published between 1988-2010), encompassing a range of outcomes, including congenital anomalies, birth weight, twinning, stillbirths, sex ratio and infant death. Their review included three earlier studies from the UK: Dummer et al. (published in 2003; study period 1956-1993) and Cresswell et al. (published in 2003; study period 1985-1999) from England, and Williams et al. (published in 1992; study period 1975-1983) from Scotland. Overall, they identified a number of higher quality studies reporting significant positive relationships with broad groups of congenital anomalies. For congenital anomalies most studies reported no association with proximity to or emissions from waste incinerators and “all anomalies”, but weak associations for neural tube and heart defects and stronger associations with facial clefts and urinary tract defects. There was limited evidence for an association between incineration and twin births and no evidence of an association with birth weight, stillbirths or sex ratio, but this may reflect the sparsity of studies exploring these outcomes. The authors concluded that the current evidence-base is inconclusive and often limited by uncertainty in exposure assessment, possible residual confounding, and lack of statistical power. A more recent review by Ncube et al. (2017) also concluded that there was insufficient evidence demonstrating a causal or non-causal relationships between residential proximity to incinerators and congenital malformations, although an earlier study identified a link between the risk of urinary tract birth defects and exposure to MSWI emissions in early pregnancy (Cordier et al., 2010). The review by Nicoll (2018) investigated the associations between environmental contaminants more generally and the occurrence of congenital heart defects. The review included reference to only one study on incinerators (Dummer et al., 2003), a retrospective cohort study which was also included in the Ashworth et al. (2014) review described above.

Vinceti et al. (2018) did not find an effect of exposure to the emissions of a municipal solid waste incinerator in Italy on rates of miscarriage or birth defects among women who lived near or were employed in the plant from 2003 to 2013. However, the authors reported limited statistical power of the estimates and absence of individual information on potential confounders. A larger multi-site Italian study examined a range of adverse birth outcomes (Candela et al. 2013) as well as the occurrence of miscarriages (Candela et al. 2015) in the vicinity of seven incinerators in northern Italy in the period 2002-2006. They found a small effect of exposure to incinerator pollution on miscarriages and preterm deliveries, but no association with sex ratio, multiple births, or frequency of small for gestational age births. Santoro et al. (2016) studied a MSWI in Tuscany, Italy, using modelled PM_{10} concentrations to identify high, medium and low exposed areas around the plant. They examined birth outcomes in residents of these areas including pre-term birth, low birth weight, small for gestational age and sex ratio for the period 2001 to 2010. They detected a weak association between exposure from MSWI and pre-term births, most evident among primiparous women. No significant results for other outcomes were found.

Kalfa et al. (2015) investigated the association of hypospadias with prenatal exposure to endocrine disruptors in a case-control study of 408 children with isolated hypospadias and 300 controls. They found that industrial areas, incinerators and waste areas were more frequent within a 3 km radius for mothers of hypospadiac boys, but no results specific to incinerators were reported.

A recent UK study carried out by Ghosh et al. (2019) investigated associations between modelled ground-level PM_{10} emitted from MSWIs within 10 km, as well as proximity of residence to a MSWI, and selected birth and infant mortality outcomes were examined for all 22 MSWIs operating in Great Britain between 2003-2010. Health outcomes in this study included term birth weight, small for gestational age at term, stillbirth, neonatal, post-neonatal and infant mortality, multiple births, sex ratio and preterm delivery. Analyses were adjusted for relevant confounders including year of birth, sex, season of birth, maternal age, deprivation, ethnicity and area characteristics. There was no excess risk in relation to any of the outcomes investigated during pregnancy or early life of modelled PM_{10} from MSWIs or proximity to an MSWI operating to current EU standards. An additional study by the same group (Freni-Sterrantino et al. 2019) did not find evidence of an association of new MSWI opening with changes in risks of infant mortality or sex ratio in comparison with control areas in England and Wales.

A study of congenital anomalies in births to mothers living within 10 km of 10 MSWIs in England and Scotland (Parkes et al. 2019) did not find evidence of an association with modelled levels of PM_{10}. However small increases in all congenital anomalies, congenital heart defects and genital anomalies were seen in those living closer to the MSWIs.

3.3. Exposure and risk assessment studies

This section examines cancer and non-cancer risk assessment studies based on measured or estimated exposures to emissions from incinerators via inhalation, ingestion or dermal contact. It also examines a small number of studies reporting emissions, exposure parameters or dispersion characteristics around MSWIs. It includes 11 studies from China and Taiwan (Ma et al., 2018; Jia et al., 2017; Ho et al., 2016; Li et al., 2015; Li et al., 2016; Li et al., 2018; Deng et al., 2016; Meng et al., 2016; Zhou et al., 2016; Shen et al., 2017; Yang et al., 2016), two studies from Italy (Scungio et al., 2015; 2016), one study from Switzerland (Setyan et al., 2017), one from the UK (Douglas et al., 2017), and three literature reviews (Johnson, 2016; Zhang et al., 2016; Jones and Harrison, 2016).

Setyan et al. (2017) measured airborne pollutants at different locations of the abatement system and the environment near two modern MSWIs in Switzerland. Their findings indicate that particle concentrations measured at the stacks were very low (<100 #/cm[3]), stressing the effectiveness of their abatement system (Fig. 3) and suggesting that the two plants released very limited amounts of particles to the surrounding areas.

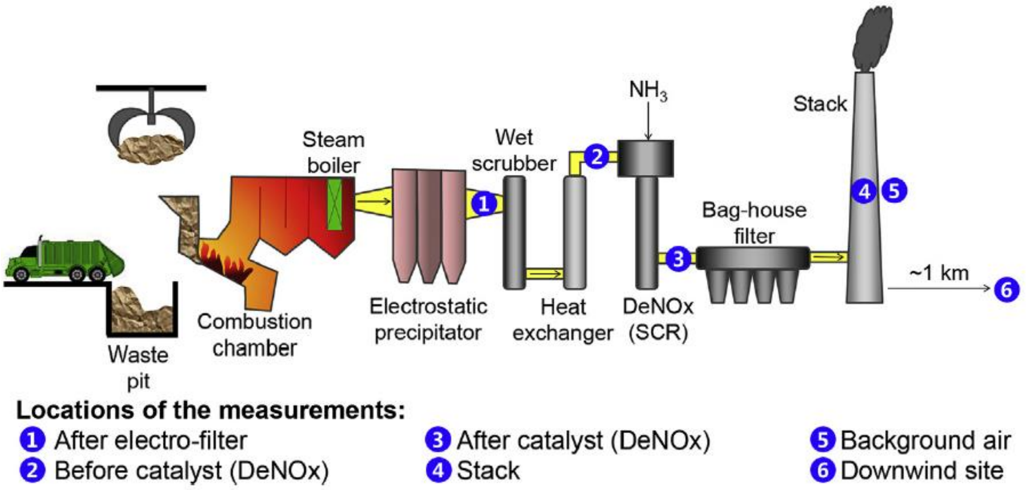


Figure 3 Locations of measurement at a MSWI plant in Switzerland (Setyan et al., 2017)

Ma et al. (2018) estimated the cancer and non-cancer risks posed to the population living around a MSWI located in north China that started operating in 2005 with a capacity of 1,200 tons of waste per day. They found that the MSWI had a major impact on Zn, Cu, Pb, Cd, and Hg contamination in soil collected within 3 km from the plant. They calculated the total exposure to heavy metals through ingestion, inhalation and dermal contact to estimate the cancer and non-cancer risks posed by heavy metals in soil around the MSWI. All hazard indexes (HIs) for the local population exceeded one, which indicated significant non-cancer risks associated with heavy metals in soil (HI: 1.50 for adult males, 1.68 for adult females, and 1.92 for children). The Incremental Lifetime Cancer Risk (ILCR)[3] for males, females and children were several orders of magnitude higher than the acceptable level (1×10^{-4}) reaching 9.40×10^{-3}, 1.02×10^{-2}, and 3.10×10^{-3}, respectively. However, the contribution of heavy metal sources other than from incineration to these risks was high, particularly for cancer risks (Fig. 4).

[3] For example, 1×10^{-6} ILCR means that there is one additional case of cancer during a lifetime in a population of a million persons.

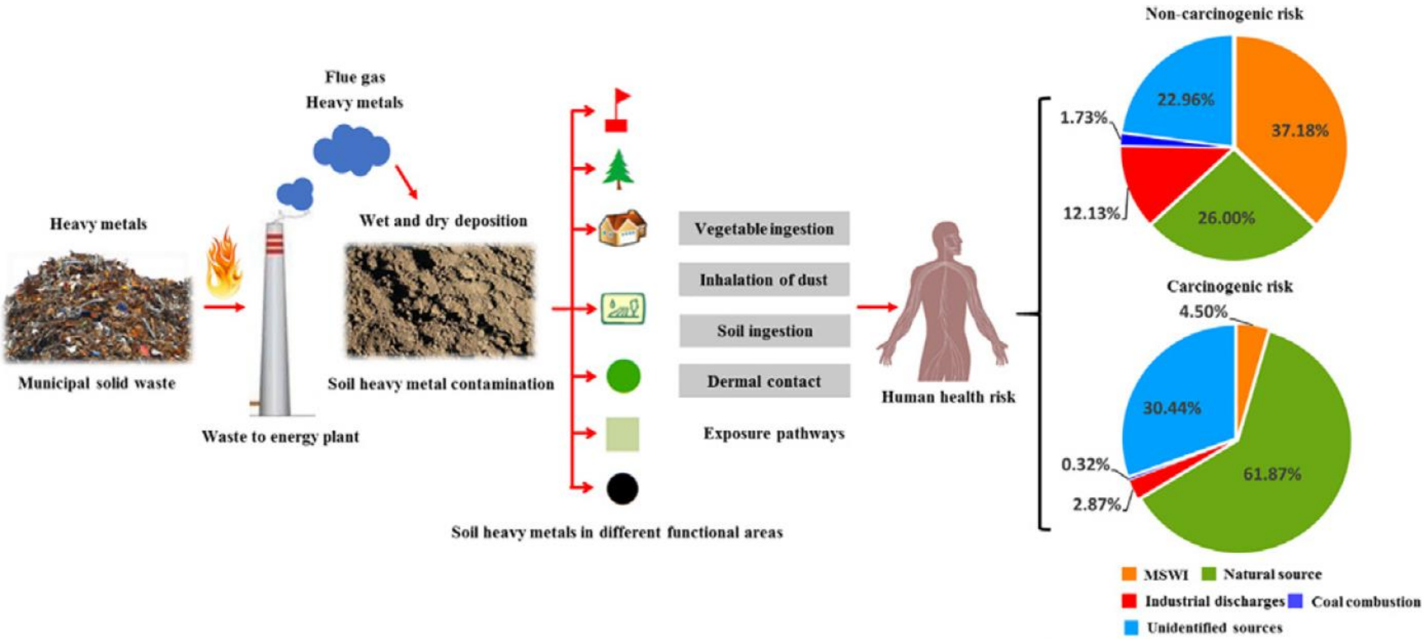


Figure 4 Contributions of different potential sources to the health risks of residents living around MSWIs (Ma et al. 2018)

Jia et al. (2017) measured concentrations of PAHs in road dust and agricultural soil samples collected from eight sites close to steel mills, chemical plants, and a municipal solid waste incinerator in suburban Shanghai, China. They estimated the ILCR for the exposed populations, which indicated that PAHs in dust and soil were associated with elevated cancer risk for children and adults via direct ingestion, while the risks via dermal contact or inhalation were lower and within acceptable levels.

Ho et al. (2016) quantified source contributions to ambient concentrations of PCDD/Fs and related inhalation cancer risk in Taipei, Taiwan, from 2003 to 2009. Three MSWIs were in the western, eastern, and south-eastern parts of the city, with average amount of waste incinerated ranging from 12,000 to 25,000 tons per month at each plant. Average waste incinerator contributions at downwind sites were significantly higher than those at the upwind sites. Downwind waste incinerator contributions decreased over the seven-year study period, and the amount of waste incinerated also decreased (from 0.57 million tons in 2003 to 0.38 million tons in 2009). This downward trend was consistent with increased recycling in Taipei that changed both the volume and composition of the incinerated waste. In this study, traffic emissions were the largest contributor (67.3%) with waste incinerators second (19.4%). The cancer risk of PCDD/Fs, based on the measured ambient concentrations averaged 1.1×10^{-6} and ranged from 1.3×10^{-7} to 8.0×10^{-6}. Thirteen out of the 14 sampling sites that had risk estimates from waste incinerators higher than 1.0×10^{-6} were in the downwind regions, highlighting the potential impacts from these point sources.

Meng et al. (2016) analysed PCDD/Fs in soil and air samples in the vicinity of two MSWIs in northern China operating since 2003 and 2008 (treating 5.95 t/d of waste for 300 days and 3.42 t/d of waste for 130 days per year), both equipped with air pollution control devices consisting of semi-dry scrubber and fabric filter to purify flue gases. Their analysis suggested that some of the soil samples were affected by the MSWIs, especially for sampling sites closer to the incinerator.

Earlier studies, in Taiwan (Cheng et al., 2003; Wang et al. 2005; Wang et al. 2008), Italy (Colombo et al., 2009; 2013), and China (Zhou et al., 2016) indicated that MSWIs are not the largest source of PCDD/Fs. Nevertheless, Oh et al. (2006) indicated the significant impact of MSWI emissions on PCDD/Fs levels in the air around a plant in Korea. This facility with treatment capacity of 200 tons/day was put into service in 1995 and retrofitted with a selective catalytic reduction reactor and bag filter in 1999.

Li et al. (2016) analysed outdoor air and fly ash samples from a MSWI (waste-to-energy) in East China. The concentrations of PCDD/Fs in outdoor air and fly ash were used to assess cancer and non-cancer risk for onsite workers and people living in adjacent villages. Li et al. (2016) used an intake methodology (including inhalation, dermal contact and accidental ingestion) for fly ash, an inhalation dosimetry methodology for outdoor air, and a probabilistic methodology for assessing health effects. They found that the lifetime cancer and non-cancer risk for onsite workers and residents were much lower than threshold values (of 10^{-6} and 1.0, respectively), suggesting no potential health risk. A later study by the same authors confirmed these findings (Li et al., 2018).

Deng et al. (2016) assessed the mercury exposure risks for a population living near the largest MSWI in South China. They assessed mercury concentrations in air, soil, and locally collected food around the MSWI, as well as in blood samples from a control group, a residential exposure group, and MSWI workers. The internal and external exposures of the subject population were analysed. Significant differences in blood concentrations of methylmercury (MeHg) were observed between the control group, the exposed group, and the MSWI workers (median levels: 0.70 mg/L, 0.81 mg/L, and 1.02 mg/L, respectively), with MeHg concentrations in blood being positively correlated with the gaseous mercury in the air. Overall, this study showed that the direct contribution of MSWI emissions was minor compared with the dietary contribution to mercury exposure. Another Chinese study which examined PCDD/F in foods collected in the vicinity of a large MSWI operating since 2003 concluded that incinerator emissions had an impact on the dietary intake of PCDD/F by the local population (Shen et al., 2017). A risk assessment study by Li et al. (2015) showed that Cd and Pb in soil samples collected near a MSWI in Guangzhou, China, resulted in the highest non-cancer risk and Cd would result in unacceptable cancer risk for children. In this case, the non-dietary intake of soil was the most important exposure pathway, when the bioaccessibility of heavy metals was taken into account.

Scungio et al. (2016) estimated the Excess Lifetime Cancer Risk (ELCR) contribution via inhalation of ultrafine and coarse particles emitted from an incinerator plant in Italy. Emissions of PM_{10}, PCDD/Fs, heavy metals (As, Cd, Ni) and PAHs were obtained from measurements and then ambient concentrations were calculated using a dispersion model. The ELCR was calculated using a probabilistic approach with realistic time-activity patterns, assuming that the plant was operating for 20 years. For all considered scenarios (i.e. dispersion conditions, stack height) and for the specific plant characteristics (i.e. electric/thermal capacity, type of waste incinerated, flue gas treatment), the maximum calculated ELCR was lower than 1×10^{-5}. A modelling study by the same group (Scungio et al., 2015) analysed the influence of different operational, environmental, and flue gas treatment parameters on ultrafine particle concentrations within 5 km from the incinerator. They showed that the most significant factor is flue gas treatment with a variation in UFP concentrations up to 370% for a plant hypothetically operating without flue gas treatment.

A relatively recent public health concern in relation with MSWIs is the incidental emissions of nanometer-sized particles (i.e. particles smaller than 1 μm in size). Smaller nanometer-sized particles (e.g. ultrafine particles or nanoparticles) may deposit in the deepest parts of the lungs, cross into the bloodstream, and affect different regions of the body. Johnson (2016) carried out a qualitative risk assessment to determine the relative risk due to incidental emissions of nanometer-sized particles from MSWIs. This study concluded that these emissions pose a low to moderate risk to individuals (i.e. workers and the public), because emission control technologies are highly effective and releases from MSWIs are typically lower than those from other sources, such as road transport. However the author acknowledged the lack of relevant toxicological data particularly for chronic exposures.

A literature review by Jones and Harrison (2016) concluded that typical ultrafine particle concentrations in MSWI flue gas are broadly similar to those in ambient air in urban areas. They concluded that, after the dispersion process dilutes incinerator exhaust with ambient air, ultrafine particle concentrations around MSWIs are "typically indistinguishable" from those that would occur in the absence of the incinerator.

4. Discussion

The volume of municipal waste generated has been increasing in most countries due to increases in population, economic growth, and a rising living standards (Ghosh et al., 2016). The amount of municipal waste going to incinerators in the UK has also substantially increased over the years. Modern MSWIs are adapted to recover energy from waste and minimise the volume of residues through the incineration process. MSWIs in the UK are currently regulated by EU Directives. The Waste Incineration Directive (2000/76/EC) was implemented in 2002 for new MSWIs and in 2005 for existing plants. In 2010, the Waste Incineration Directive (2000/76/EC) was transposed into the Industrial Emissions Directive (2010/75/EU) which was implemented in the UK in 2013 for new MSWIs and in 2014 for existing facilities (Douglas et al., 2017). Following these regulations, modern MSWIs in the UK operate with the best available technologies to ensure high energy efficiency in the incineration process and low pollutant emissions to the environment. The Industrial Emissions Directive contains emission limit values for incineration plants, including limits for gases, particles, heavy metals and dioxins/furans. Incinerator operators in the UK are required to monitor (continuously or periodically) emissions and make monitoring data available to the regulator.

There have been many published studies assessing the impact of MSWIs on the environment and human health in different countries. We have identified 35 relevant studies published in the last 5 years mainly focused on levels of pollutants (PCDD/Fs, metals, etc.) in the air and soil around incinerators, and the assessment of related population exposure and health risks (cancer and non-cancer). Most of these studies came from China and Spain. There have been very few original epidemiological studies, three from the UK and three from Italy (Freni-Sterrantino et al. 2019; Ghosh et al. 2019; Parkes et al. 2019; Candela et al. 2015; Vinceti et al. 2018; Santoro et al, 2016) published within this period, focusing on adverse pregnancy, birth and neonatal outcomes. Earlier epidemiological studies mainly focused on adult cancers (Elliot et al. 1996; 2000), but we did not find any relevant epidemiological studies on cancer published in the last 5 years.

We identified six literature reviews of varied quality published within the last 5 years (Ashworth et al., 2014; Jones and Harrison, 2016; Zhang et al., 2016; Wielgosiński and Targaszewska, 2014; Ncube et al., 2017; Johnson, 2016). However, three of these reviews focused on emissions from MSWIs rather than on health effects (Jones and Harrison, 2016; Johnson, 2016; Zhang et al., 2016). Earlier literature reviews that examined health effects associated with different solid waste management options, including incineration, were published by Crowley et al. (2003), Porta et al. (2009), Rushton (2003), Franchini et al. (2004), Hu and Shy (2001), and Thompson and Anthony (2008). Evidence from these earlier reviews is not formally included in the present report, but some of their findings were discussed in the more recent, high quality review by Ashworth et al. (2014).

The BSEM report on the Health Effects of Waste Incinerators (Thompson and Anthony, 2008), which was published prior to our inclusion period, argued that: (a) incinerators are a major source of fine particulates, of toxic metals and organic chemicals, including known carcinogens, mutagens, and hormone disrupters; and (b) epidemiological studies have shown higher rates of adult and childhood cancer and birth defects around municipal waste incinerators. In the recent scientific literature we examined (published in the last 5 years), we did not find consistent evidence supporting either of these two statements in relation to modern MSWIs. Modern plants operating in the UK under the Industrial Emissions Directive have very low emissions to the environment that may only marginally increase population exposure to pollutants and related health risks.

The reviewed epidemiological evidence in relation to cancer points at significant increases in sarcomas and lymphomas cases associated with exposure to dioxins from old (pre-2000) waste incinerators in Italy (Zambon et al. 2007; Biggeri and Catelan, 2005) and Spain (Garcia-Perez et al., 2013). However, dioxin levels were not generally monitored as part of these studies, therefore exposures were only estimated approximately. More recent studies have shown very significant decreases in exposure to organochlorines (including PCDD/Fs and PCBs) near modern MSWIs (post-2005) (Zubero et al., 2017).

A number of recent exposure/risk assessment studies, mostly from China, have estimated cancer risk based on measured or modelled exposures to heavy metals (Ma et al., 2018), PAHs (Jia et al., 2017), and PCDD/Fs (Ho et al. 2016), using Incremental/Excess Lifetime Cancer Risk (I/ELCR) calculation approaches. The calculated I/ELCR were in several cases in exceedance of the acceptable levels of 1.0×10^{-6} to 1.0×10^{-4} (Ma et al., 2018; Jia et al., 2017), particularly downwind from the incineration plants (Ho et al., 2016). However, these exposures were also related to pollution sources other than incineration (e.g. industry, energy generation), and multiple exposure pathways (ingestion, dermal, inhalation) for heavy metals and PAHs. Health risks associated with MSWIs may not be limited to direct exposure to air and soil pollution. For example, consumption of locally grown food may be a significant exposure route to PCDD/Fs and heavy metals such as mercury from MSWIs (Deng et al., 2016). Lower cancer risks associated with PCDD/Fs exposure from incinerators were estimated in two studies from East China (Li et al., 2016) and Italy (Scungio et al., 2016).

Although there is limited information about the specific MSWI plants studied in China, it is unlikely that they operated under a similarly stringent regulatory regime as the one that currently applies to MSWIs in the UK. Based on the reported exposures and risks estimates, and the declining MSWI emission trends overall, we can conclude that the direct cancer risks associated with modern MSWIs in the UK are currently very low. However, given the relatively high PCDD/Fs levels in soils around MSWIs found in other countries, it is plausible that legacy contamination from older MSWIs could affect current population exposure levels due to soil re-suspension or ingestion. Furthermore, bearing in mind that the minimum induction periods for cancers is generally 10 years for solid tumours and 1 year for leukaemia (Garcia-Perez et al., 2013), it may take a number of years for new epidemiological evidence to emerge in relation to modern MSWIs.

Earlier epidemiological studies examining adverse pregnancy, birth and neonatal outcomes have shown association of MSWIs emissions with a number of outcomes, including neural tube and heart defect, facial clefts and urinary tract defects, and miscarriages and preterm deliveries. However this evidence is inconsistent and related to older plants. The recent, high quality studies in Great Britain (Ghosh et al., 2019; Freni-Sterrantino et al., 2019; Parkes et al. 2019) did not find evidence of an association between emissions from MSWIs and adverse pregnancy, birth or neonatal outcomes. However, Parkes et al. (2019) found small excess risks associated with congenital heart defects and genital anomalies in proximity to MSWIs. These latest findings may reflect incomplete control for confounding, but a possible causal effect could not be excluded.

Primary emissions from well-managed modern MSWIs with appropriate air pollution abatement technologies are generally very low compared with to other outdoor sources of the same pollutants (Buonanno and Morawska, 2015; Johnson, 2016; Jones and Harrison, 2016). However, secondary particles from MSWI emissions, as well as emissions from heavy duty traffic generated by the plants (e.g. for waste delivery), are topics that need further research. The current legislative regime minimises the potential for population exposure to MSWI emissions; however if exceedances of emission limits occur, this may pose a health risk to exposed populations.

It is therefore recommended that exposure assessment methods include atmospheric dispersion modelling with realistic emission estimates, including from potential increases in heavy duty traffic, and consider multiple exposure pathways (Ashworth et al., 2014). Additionally multi-site MSWI studies with clearly defined health outcomes and validation of exposure through human biomonitoring are recommended in order to increase confidence in the epidemiological findings.

5. Conclusions

The reviewed evidence suggests that well-managed modern MSWIs are unlikely to pose a significant health risk (cancer, non-cancer, pregnancy, birth and neonatal health) in the UK under the current stringent regulatory regime. Recent studies (published within the last 5 years) in the UK and internationally have not found consistent epidemiological evidence of health effects associated with modern MSWIs. However, risk assessment studies have in some cases (mainly in China) estimated cancer risks that exceed recommended ranges. The comparability of the plants included in these studies with modern MSWIs currently operating in the UK is unclear.

A recent large study (Ghosh et al., 2019; Freni-Sterrantino et al., 2019) did not find evidence of an association of MSWIs in Great Britain with adverse pregnancy, birth and neonatal outcomes. Earlier studies (Elliot et al. 1996; 2000) did not find convincing evidence of an association of proximity to older incinerators in Great Britain with cancer outcomes. Although there is limited evidence of an association of proximity to older incinerators, or exposure to dioxins, with sarcoma and lymphoma risk in other countries, the very substantial decrease in dioxin emissions from MSWIs over recent years is likely to make these risks negligible for populations living in the vicinity of modern, well-controlled plants in the UK.

It should be acknowledged that several epidemiological studies had a number of limitations, including small population sample size, limited control for confounding factors, insufficient accounting for latency periods, and the use of distance-based surrogates for exposure assessment. In some studies in which risk excesses were found, alternative interpretations, for example involving exposures from sources other than waste incineration were plausible. It is important to point out that stack emissions from modern MSWIs are much reduced compared to old generation plants (WHO, 2007). Future epidemiological studies will benefit from exposure assessment methods based on atmospheric dispersion modelling, potentially validated through human biomonitoring, clearly defined health outcomes, and robust control of possible confounding factors.

On the basis of this review, we conclude that any potential health risks associated with direct emissions from modern, effectively managed and regulated MSWIs in London are exceedingly low. However, consideration should be given to secondary pollutant formation, as well as to emissions from additional heavy duty traffic potentially generated in the vicinity of the plants. It is recommended that potential health risks from MSWIs be individually assessed, due to the technical, operational and locational differences between facilities (Domingo et al., 2015).

Minimising waste generation, maximising recycling and re-use, and limiting incineration to non-recyclable materials, are key priorities for sustainable development. However, this review did not consider the comparative health risks or benefits of different waste management options. Furthermore, the overall impact of waste incineration on the environment and human health through a combination of direct and indirect mechanisms was not evaluated. Finally, the impact of MSWIs on health inequalities in London was beyond the scope of this review.

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