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Adverse reproductive outcomes associated with exposure to a municipal solid waste incinerator.

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Author information

Abstract

INTRODUCTION:

The association between reproductive health outcomes and exposure to municipal solid waste incinerators (MSWIs) is inconclusive. This study investigates the association between exposure to a MSWI and various reproductive outcomes (preterm birth, low birth weight, small for gestational age, and sex ratio), taking into account other sources of pollution (industrial plants, highway, major roads with high traffic flows) and maternal factors, including the socioeconomic status.

METHODS:

PM10 concentration maps were used for the exposure assessment to the MSWI and to other sources of pollution in the study area. Information on resident births and maternal covariates were selected from the delivery certificates referred to the period 2001-2010. Mothers' addresses were geocoded in order to attribute the individual level of exposure. Odds ratios (ORs) with a 95% confidence interval (CI) adjusted for maternal covariates and exposure to other pollution sources were calculated.

RESULTS:

A total of 3153 newborns to 2401 mothers residing in area during the study period were analyzed. A risk of preterm birth associated with increased exposure was detected (OR = 1.61; 95% CI: 0.88-2.94; p test for trend 0.098). When newborns to primiparous women were considered an OR of 2.18 (95% CI: 1.05-4.53) and a significant trend were observed (p = 0.033). No significant results for the other investigated outcomes were observed.

CONCLUSIONS:

The study detected a slight association between exposure at MSWI and preterm births. The results are in agreement with those of a previous multi-site study with similar design, and they

strengthen the recommendation to consider gestational age in studies and surveillance in areas with MSWIs and similar sources of pollution.

Epidemiology. 2013 Nov;24(6):863-70. doi: 10.1097/EDE.0b013e3182a712f1.

Air pollution from incinerators and reproductive outcomes: a multisite study.

Candela S[1], Ranzi A, Bonvicini L, Baldacchini F, Marzaroli P, Evangelista A, Luberto F, Carretta E, Angelini P, Sterrantino AF, Broccoli S, Cordioli M, Ancona C, Forastiere F.

Author information

Abstract

BACKGROUND:

The few studies that have investigated the relationship between emissions from municipal solid-waste incinerators and adverse pregnancy outcomes have had conflicting results. We conducted a study to assess the effects of air emissions from the eight incinerators currently in operation in the Emilia-Romagna Region of Italy on reproductive outcomes (sex ratio, multiple births, preterm births, and small for gestational age [SGA] births).

METHODS:

We considered all births (n = 21,517) to women residing within a 4-km radius of an incinerator at the time of delivery during the period 2003-2010 who were successfully linked to the Delivery Certificate database. This source also provided information on maternal characteristics and deliveries. Each newborn was georeferenced and characterized by a specific level of exposure to incinerator emissions, categorized in quintiles of PM10, and other sources of pollution (NOx quartiles), evaluated by means of ADMS-Urban system dispersion models. We ran logistic regression models for each outcome, adjusting for exposure to other pollution sources and maternal covariates.

RESULTS:

Incinerator pollution was not associated with sex ratio, multiple births, or frequency of SGA. Preterm delivery increased with increasing exposure (test for trend, P < 0.001); for the highest versus the lowest quintile exposure, the odds ratio was 1.30 (95% confidence interval = 1.08-1.57). A similar trend was observed for very preterm babies. Several sensitivity analyses did not alter these results.

CONCLUSIONS:

Maternal exposure to incinerator emissions, even at very low levels, was associated with preterm delivery.

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Environ Int. 2014 Aug;69:120-32. doi: 10.1016/j.envint.2014.04.003. Epub 2014 May 12.

Waste incineration and adverse birth and neonatal outcomes: a systematic review.

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Author information

Abstract

BACKGROUND:

Public concern about potential health risks associated with incineration has prompted studies to investigate the relationship between incineration and risk of cancer, and more recently, birth outcomes. We conducted a systematic review of epidemiologic studies evaluating the relationship between waste incineration and the risk of adverse birth and neonatal outcomes.

METHODS:

Literature searches were performed within the MEDLINE database, through PubMed and Ovid interfaces, for the search terms; incineration, birth, reproduction, neonatal, congenital anomalies and all related terms. Here we discuss and critically evaluate the findings of these studies.

RESULTS:

A comprehensive literature search yielded fourteen studies, encompassing a range of outcomes (including congenital anomalies, birth weight, twinning, stillbirths, sex ratio and infant death), exposure assessment methods and study designs. 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 is limited evidence for an association between incineration and twinning and no evidence of an association with birth weight, stillbirths or sex ratio, but this may reflect the sparsity of studies exploring these outcomes.

CONCLUSIONS:

The current evidence-base is inconclusive and often limited by problems of exposure assessment, possible residual confounding, lack of statistical power with variability in study design and outcomes. However, we identified a number of higher quality studies reporting significant positive relationships with broad groups of congenital anomalies, warranting further investigation. Future studies should address the identified limitations in order to help improve our understanding of any potential adverse birth outcomes associated with incineration, particularly focussing on broad groups of anomalies, to inform risk assessment and waste policy.

KEYWORDS:

Birth; Incineration; Incinerators; Neonatal; Review; Waste

Environ Health. 2009 Dec 23;8:60. doi: 10.1186/1476-069X-8-60.

Systematic review of epidemiological studies on health effects associated with management of solid waste.

Porta D[1], Milani S, Lazzarino AI, Perucci CA, Forastiere F.

Author information

Abstract

BACKGROUND:

Management of solid waste (mainly landfills and incineration) releases a number of toxic substances, most in small quantities and at extremely low levels. Because of the wide range of pollutants, the different pathways of exposure, long-term low-level exposure, and the potential for synergism among the pollutants, concerns remain about potential health effects but there are many uncertainties involved in the assessment. Our aim was to systematically review the available epidemiological literature on the health effects in the vicinity of landfills and incinerators and among workers at waste processing plants to derive usable excess risk estimates for health impact assessment.

METHODS:

We examined the published, peer-reviewed literature addressing health effects of waste management between 1983 and 2008. For each paper, we examined the study design and assessed potential biases in the effect estimates. We evaluated the overall evidence and graded the associated uncertainties.

RESULTS:

In most cases the overall evidence was inadequate to establish a relationship between a specific waste process and health effects; the evidence from occupational studies was not sufficient to make an overall assessment. For community studies, at least for some processes, there was limited evidence of a causal relationship and a few studies were selected for a quantitative evaluation. In particular, for populations living within two kilometres of landfills there was limited evidence of congenital anomalies and low birth weight with excess risk of 2 percent and 6 percent, respectively. The excess risk tended to be higher when sites dealing with toxic wastes were considered. For populations living within three kilometres of old incinerators, there was limited evidence of an increased risk of cancer, with an estimated excess risk of 3.5 percent. The confidence in the evaluation and in the estimated excess risk tended to be higher for specific cancer forms such as non-Hodgkin's lymphoma and soft tissue sarcoma than for other cancers.-

CONCLUSIONS:

The studies we have reviewed suffer from many limitations due to poor exposure assessment, ecological level of analysis, and lack of information on relevant confounders. With a moderate level confidence, however, we have derived some effect estimates that could be used for health impact assessment of old landfill and incineration plants. The uncertainties surrounding these numbers should be considered carefully when health effects are estimated. It is clear that future research into the health risks of waste management needs to overcome current limitations.

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PMCID: PMC3129292

Health impact assessment of waste management facilities in three European countries

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Abstract

Background

Policies on waste disposal in Europe are heterogeneous and rapidly changing, with potential health implications that are largely unknown. We conducted a health impact assessment of landfilling and incineration in three European countries: Italy, Slovakia and England.

Methods

A total of 49 (Italy), 2 (Slovakia), and 11 (England) incinerators were operating in 2001 while for landfills the figures were 619, 121 and 232, respectively. The study population consisted of residents living within 3 km of an incinerator and 2 km of a landfill. Excess risk estimates from epidemiological studies were used, combined with air pollution dispersion modelling for particulate matter (PM_{10}) and nitrogen dioxide (NO_2). For incinerators, we estimated attributable cancer incidence and years of life lost (YoLL), while for landfills we estimated attributable cases of congenital anomalies and low birth weight infants.

Results

About 1,000,000, 16,000, and 1,200,000 subjects lived close to incinerators in Italy, Slovakia and England, respectively. The additional contribution to NO_2 levels within a 3 km radius was 0.23, 0.15, and 0.14 $\mu g/m^3$, respectively. Lower values were found for PM_{10}. Assuming that the incinerators continue to operate until 2020, we are moderately confident that the annual number of cancer cases due to exposure in 2001-2020 will reach 11, 0, and 7 in 2020 and then decline to 0 in the three countries in 2050. We are moderately confident that by 2050, the attributable impact on the 2001 cohort of residents will be 3,621 (Italy), 37 (Slovakia) and 3,966 (England) YoLL. The total exposed population to landfills was 1,350,000, 329,000, and 1,425,000 subjects, respectively. We are moderately confident that the annual additional cases of congenital anomalies up to 2030 will be approximately 2, 2, and 3 whereas there will be 42, 13, and 59 additional low-birth weight newborns, respectively.

Conclusions

The current health impacts of landfilling and incineration can be characterized as moderate when compared to other sources of environmental pollution, e.g. traffic or industrial emissions, that have an impact on public health. There are several uncertainties and critical assumptions in the assessment model, but it provides insight into the relative health impact attributable to waste management.

Go to:

Background

Waste collection, transport, processing, and disposal are important for both environmental and public health reasons. Different strategies have been proposed to reduce, reuse, recycle, recover energy and finally dispose of municipal solid waste (MSW) [1,2] but the environmental impacts of these strategies are controversial [3]. Several studies of the possible health effects on populations living in proximity of landfills and incinerators have been published [4] and both landfills and incinerators have been associated with some reproductive and cancer outcomes. However, the results of these studies are either inconclusive or contradictory. Consequently, there is controversy over the possible health implications of waste management policies [5] and both policy makers and the public require more information on the likely health impacts (and importantly, the associated nature and extent of the uncertainties).

Within the EU-funded INTARESE project [6], we aimed at assessing potential exposures and health effects arising from municipal solid wastes, from generation to disposal, or treatment (see Figure Figure11 to appreciate the full chain of the waste problem). The background of the project is that policy cannot be served solely by using traditional risk assessment methods. Instead, the assessment needs an approach that recognises the complexity of the systems involved, and integrates the different information, knowledge, analytical methods and tools needed to approach the way these complex systems behave. It was this need that motivated the term "integrated environmental health impact assessment" (IEHIA), whose rationale, guidance and instruments are illustrated in the toolbox available on the web (http://www.integrated-assessment.eu).

Figure 1

The full chain approach - from waste production to health effects.

We performed a diagnostic assessment for three EU countries (Italy, Slovakia and England) considering the baseline situation in 2001 in order to assess the health burden or risk attributable to specified factors. This initial approach might be of interest for ranking different risks to health in terms of their overall burden of disease, and thus for prioritising policy action. For reasons of feasibility in our study, not all the aspects illustrated have been considered here (e.g. waste transport, occupational factors, greenhouse gases, risk perception etc) and they could be part of a more complete and exhaustive exercise. However, we aimed to establish a baseline scenario that can be useful in the future for prognostic assessment of different policy options.

Each step in the exercise has several uncertainties that should be considered in the overall evaluation. For this reason, we have tried to systematically state the level of confidence we had using the scale of calibrated terminology used by the IPCC [7]: very high (at least 9 out of 10), high (about 8 out of 10), moderate (about 5 out of 10), low (about 2 out of 10), and very low (less than 1 out of 10). Such calibrated levels of confidence can be used to characterize uncertainty based on expert judgment of the correctness of a model, an analysis or a statement. The approach was also applied in the systematic review we conducted on the topic [4].

Go to:

Methods

The assessment followed the steps involved in the "full chain" approach, illustrated in Figure Figure11.

Waste Generation and Management

Current waste management data were collected from country-specific environmental agencies. The Italian Institute for Environmental Protection and Research (ISPRA) [8] provided a database of the incinerators operating during the period 2001-2007. In addition, a detailed census of the 52 incinerators operating in 2005 was made available by a national research institute [9]. Detailed data were also provided by the regional environmental authority of Emilia Romagna for all eight incinerators located in that region. From all these sources, we were able to identify the 40 incineration plants operating in 2001, obtain their geographical coordinates and get specific information on years of operation, number of lines, fumes capacity (Nmc/h), stack height (m), stack diameter (m), exit velocity (m/s), emission rate (m^3/s), and exit temperature (°C). In a few cases, when the information on technical characteristics was missing, it was approximated using information from other plants with similar characteristics.

The ISPRA provided a database of landfills in Italy (a total of 619 in 2001) with information of the total capacity and wasteland filled per year. Geographical coordinates of the landfills were available for only five (of twenty) regions (Piedmont and Emilia Romagna (North), Tuscany and Abruzzi (Centre), and Campania (South)) for a total of 118 landfills. For the rest of the country, we assumed that the characteristics (sex, age and socioeconomic status) of people around the 501 missing landfills were similar to those of the entire sample of the 118 sites studied.

For Slovakia, information on the number of incinerators handling municipal waste in 2001 was obtained from the Slovak Environmental Agency (SEA). There were two incinerators for MSW in 2001, geo-coded and with detailed information on technical characteristics, obtained from managing companies. At the end of 2001, there were 165 active landfills for municipal wastes. The list of landfills, by region, was available from the website of the Slovak Ministry of Environment [10], with geographical coordinates, capacity and starting year obtained from the SEA. Out of 165 active landfills in 2001, 121 were geocoded. We assumed that the characteristics (sex, age and socioeconomic status) of people around the 45 missing landfills were similar to those of the 121 studied sites.

For England, we evaluated all 11 municipal waste incinerators operating during 2001. Data on emissions of toxic substances (Tonnes/annum) and location (x- and y-coordinates) were obtained from the Environment Agency (EA). Wherever possible, more specific data (e.g. stack height, stack diameter, emission rate, etc) were obtained from the waste companies' websites. Where no data could be found, we applied an average from the known incinerator data.

Data for all regulated landfill sites in England and Wales was obtained from the EA. No data for 2001 was available because of changes in the regulations. In 2001 landfill sites came under a different directive and were not required to report to the EA under the Pollution Prevention and Control (PPC) Regulations. The EA advised using the 2006 landfill data instead as a good indicator for the 2001 situation [11]. The 2006 dataset contains information about 242 regulated landfill sites (e.g. geographic Cartesian coordinates, atmospheric releases).

Population data by gender, age and socioeconomic status

Population data at the smallest unit of aggregation for the 2001 census were available for the census blocks in Italy (about 100-200 (mean 162, sd 223) inhabitants per unit) and Slovakia (about 700-800 (mean 785, sd 1318) inhabitants). For England, census population data were disaggregated to postcode areas (mean 41, sd 37). For each census block in Italy, a deprivation index was available [12]. It used census information that represents various aspects of deprivation: education, occupation, home ownership, family composition and nationality. An algebraic combination of these factors was used to create an index of socioeconomic position by census block, with the corresponding population distributed in quintiles, ranging from very well off (level 1) to very underprivileged (level 5). For Slovakia, an index of socioeconomic position was derived from the following census variables: education (proportion of population with university, secondary, basic or no education), proportion of families with children, proportion of employed among 16-64 year olds, house type (house or flat), and house ownership. Again an index per census block was distributed in quintiles, ranging from very well off (level 1) to very underprivileged (level 5). For England, the Carstairs score [13], which is based on four census variables (lack of car ownership, unemployed head of the household, low social class and overcrowding) was applied as the deprivation index. The Carstairs score was available at the smallest census area, the output areas (OAs). By means of a point-in-polygon analysis the Carstairs score was transferred from the OA to each postcode. As in Italy and Slovakia, the Carstairs score in England was divided into 5 quintiles, 1 being the most affluent to 5 being the most deprived.

We used the distance from the point source (landfill site and/or incinerator) to estimate the exposed population. We decided to use the 3 km surrounding incinerators [14] and 2 km surrounding landfill sites [15] as the likely limit of the dispersion of emissions. For both incinerators and landfills, we defined increasing radial distances (1, 2, and 3 km) from the centre (the formal address of the plant) and evaluated the census blocks (or the postcode districts) that matched these locations. In several cases, the distribution of census blocks did not precisely fit the circle and the borders were tailored in order to more precisely count the population. The validity of the method has been evaluated using individually geocoded data of the resident population in four areas of Emilia Romagna (Italy) and considering the border of the plant area rather than the formal address: the error range was between 1 and 10%.

Local air dispersion modelling

Local air dispersion modelling was used to calculate increased pollutant concentrations (particulate matter, PM_{10}, and Nitrogen dioxide, NO_2) within 3 km of the waste incinerators. Dispersion modelling for incinerators was based on the national information on incineration census, actual waste throughput data and meteorological data. We have used the Atmospheric Dispersion Modelling System (ADMS-Urban) [16] for modelling dispersion at the local scale for 40 incinerators in Italy, 2 in Slovakia and 11 in England. Meteorological data requirements include temperature (°C), wind speed (m/s), wind direction (°), precipitation (mm), cloud cover (oktas), relative humidity (%), boundary layer height (m), and surface sensible heat flux (W/m^2). We have used official meteorological data available from the nearest meteorological station. Usually 2001 meteorological data were used.

For PM_{10} and NO_2 we have used emission rates based on national limits derived from EU legislation in 2001, namely daily emission rates of 10 and 200 mg/Nm^3, respectively. However, since actual emissions could be estimated from Italy and England, we conducted an additional analysis using this measurement data [17,18].

A number of incinerators in both Italy and England were located on hilly terrain. ADMS-Urban contains a hill module that takes into account the surrounding terrain when modelling the dispersion. Terrain data was therefore obtained for both these countries. For England the Ordnance Survey PANORAMA ™ Digital Terrain Model was used to obtain surface heights for 50 × 50 m cells up to 10 km away from 8 of the 17 incinerators. For Italy the terrain data was collected from the Italian Environmental Protection Agency for 35 of the 40 incinerators.

ADMS air pollution dispersion model provided "contours" of additional concentrations of PM_{10} and NO_2 for the incinerators. These output files (one per country) have been transferred into the GIS system. The population database at the smallest available unit (i.e. census block or postcode district) for the given radius of 3 km has been added to the GIS as another data layer. Using an overlay function in GIS, the population data was combined with the air pollution concentration data with a grid of 200 meters. In this way, different statistics regarding population-weighted exposure levels have been estimated according to gender, age and socioeconomic status.

Exposure-response relationships

Following a systematic review of the literature [4], we chose to use the excess risk values reported by Elliott et al. [14] of cancer for incinerators, and of congenital malformations and low birth weights [15] for landfills. Cancer incidence between 1974 and 1987 among over 14 million people living near 72 solid waste incinerator plants in Great Britain were studied [14]. The excess risk estimate for living within 3 km of an incinerator for all cancers combined was 3.5% (95%CI = 3-4%). However, Elliott et al. point out that there was an indication of residual confounding from socioeconomic status and a concern of misdiagnosis among registrations and death certificates for liver cancer. These aspects lowered our overall confidence in the results and we rated the level of confidence of the risk estimates for cancer as "moderate".

In the national study conducted by Elliott et al. [15] on 9,565 landfill sites in Great Britain, operational at some time between 1982 and 1997, statistically significant increased risks were found for all congenital malformations, neural tube defects, abdominal wall defects, surgical correction of gastroschisis and exomphalos, and low and very low birth weight in residents within 2 km of the sites. Although several alternative explanations, including ascertainment

bias, and residual confounding could not be excluded in the study, it provides quantitative effect estimates: the relative risk for congenital anomalies was 1.02 (99% CI = 1.01-1.03) and 1.06 (99% CI = 1.052-1.062) for low birth weight. Again, on the basis of the systematic review [4] our level of confidence in these relative risks was "moderate".

Linear and no-threshold exposure-response functions related to the long-term effects on mortality from PM_{10} and NO_2 have been derived from the extensive existing reviews of epidemiological and toxicological data [19]. We assumed a linear relationship between the air pollutants and associated health effects as most epidemiological studies on large populations have been unable to identify a threshold concentration below which ambient air pollutants has no effect on morbidity and mortality. The following values were used:

RR = 1.06 (95%CI = 1.03–1.09) increase in mortality for 10 $\mu g/m^3 PM_{10}$

RR = 1.06 (95%CI = 1.04–1.08) increase in mortality for 10 $\mu g/m^3 NO_2$

Background health statistics

Background gender-age specific cancer incidence data for the three countries were retrieved [20-22] together with national mortality statistics [22-24]. Prevalence of congenital malformations at birth was derived from the Annual Report (data for 2000) of the International Clearinghouse for birth defects monitoring system [25] for Italy and England, and from The Statistical Office of the Slovak Republic [24] for Slovakia.

Time frame of the assessment

Health impacts were estimated for the period 2001-2050, assuming that the incinerators operating in 2001 will be operating until 2020 - a realistic assumption given that these plants are usually in operation for a long time. The choice of 2050 ensures that the time period under consideration is long enough to account for chronic effects. For incinerators, cancer incidence "attributable" to exposure before 2001 ("past exposure") was estimated (burden of disease non-modifiable by policy) as it is likely that it will continue to appear until 2050. In addition, cancer incidence "attributable" to exposure during 2001-2020 was estimated ("current exposure") as these effects could be, at least in part, prevented. In addition, Years of Life Lost (YoLL) were estimated as attributable to current exposure (2001-2020) to PM_{10} and NO_2 in the cohort of 2001 residents followed up to 2050.

For landfills operating in 2001, we assumed that the emissions will last up to 2030 (an assumption supported by the available knowledge that landfilled biodegradable waste starts to emit biogas a few years after deposit and continues to do so for several decades) and the health effects, in terms of congenital anomalies and low birth weight, are constant throughout this period. It was assumed that there would be no improvement in the technology of gas recovery. Of course, the same could be applied to contamination of groundwater and soil.

Estimating cancer incidence near incinerators

The basic formula to compute the number of cancer cases attributable to an incinerator is:

$$AC = Rate_{unex} * ER * Pop_{exp}$$

where AC = the attributable cancer incidence

$Rate_{unex}$ = background incidence rate in the general population

ER = excess risk in the exposed population (relative risk - 1)

Pop_{exp} = number of exposed people

We assumed that the excess risk is not constant over time, but varies for a specific individual of the population at a given age and specific time as a function of various characteristics: level of cumulative exposure, latency since first exposure and latency since cessation of exposure (if any). We therefore assumed a theoretical model of cancer occurrence and imputed the varying excess risk around different incinerators, as a function of the different characteristics of the plant and of the nearby population. The methods are fully described in the additional file 1 (Appendix 1). Briefly, we modified the excess risk for overall cancer incidence estimated by Elliott et al. [14] (i.e. 3.5% for people exposed at incinerators operating before 1980, assuming 20 years of exposure) as a function of cumulative exposure (with exposure coefficients varying with time), latency since first exposure and latency since cessation of exposure. This algorithm was applied to the estimated 2001 population (by gender and age) living within 3 km of each specific incinerator to estimate the number of excess cancer cases in 2001-2050 attributable to exposures before 2001 and during 2001-2020. In Appendix 1, we illustrate the basic assumptions and we show how the excess risk during the 2001-2050 evaluation period varies in relation to time since the start of the operation of the plant and the time since cessation. The key assumption we made is that after 1980, due to technological improvements and as a result of national and European laws, the emissions from incinerators were reduced. For instance, measured particulate matter emissions from one incinerator in Italy (Modena) were 0.19 g/s in 1980-1989 (two lines), 0.0347 and 0.0376 g/s in 1995-1996 (two lines), 0.0196, 0.0273 and 0.104 g/s (three lines) in 1997-2002, and 0.0081, 0.0101, and 0.013 g/s (three lines) in 2003-2006. On the other hand, emission limits in the UK were reduced through legislation from 460 mg/m^3 (1968) to 200 mg/m3 (1983) to 30 mg/m^3 (1989/1990) and finally to 10 mg/m^3 in 2000. Based on these data, we assumed that if the exposure level was 1 before 1980, it was 0.8 in 1980-1989, 0.2 in 1990-2000, and 0.05 after 2000. In other words, we are assuming that the exposure levels during the eighties were somewhat lower (0.8) than during the seventies, during the nineties were fourfold lower, and in more recently they were twentyfold lower than in the seventies. We are highly confident about the scores we gave the exposure levels, as they are confirmed from measured data and are reflected in the legislation. Overall, we have a moderate level of confidence in the estimates of cancer cases, mainly due to the uncertainty characterizing the excess risk used.

Estimating years of life lost (YoLL)

Assuming that chronic effects may continue to manifest themselves until 2050 in the entire population living close to incinerators in the three countries in 2001, and that their mortality rate was similar to that of the national population in 2001, we estimated Years of Life Lost attributable to PM_{10} and NO_2 exposure as derived from the air dispersion model. In particular, we assumed that the impact of PM_{10} and NO_2 was that which occurs during 2001-2020. As was done by Miller [26], we assumed constant future birth rates, constant hazard rates over time, immediate mortality effects after change in population-weighted exposure (no lag). The effects are calculated up to the year 2050 and all over a whole life span (105 years).

Overall, we have a high level of confidence in the estimates of YoLL, mainly due to the rather stable and well-established coefficients for NO_2 and PM_{10}.

Estimating congenital anomalies and low birth weight near landfills

With a moderate level of confidence, we assumed that the only health impacts on populations living near landfills are congenital malformations and low birth weight. Other possible health effects were not considered, as our review of the literature did not reveal any other significant health effects. As already indicated, the time of the evaluation was 2001-2030 on the assumption that gas emissions (methane, carbon dioxide, non-methane volatile organic compounds, hydrogen sulfide and ammonia) from landfills last several years even after a landfill closure (we assumed 30 years). We cannot exclude that the effect on reproductive health occurs via groundwater or soil contamination. The formula to calculate the cases of malformation and babies of low birth weight attributable to residence near landfills is the same as for cancer incidence, where incidence should be changed with prevalence at birth and the number exposed are newborns.

Overall, we have a moderate level of confidence in the estimates of attributable cases of congenital anomalies and low birth weight, mainly due to the uncertainty in characterizing the excess risk ratios.

Go to:

Results

Waste generation and management

Table Table11 illustrates the basic statistics of waste management in Italy, Slovakia and England in 2001. The amount of MSW produced in Italy in 2001 was 31.94 million tonnes (Mtonnes), which corresponds to 560 kilograms per inhabitant. About 56% of Italian MSW was directed to landfills; recycling and composting accounted for 16% and 8% of MSW. For Slovakia, data on MSW production and management were available for 2002. The amount of MSW produced in that year was 1.52 million tonnes, which corresponds to 283 kilograms per inhabitant. From this total, 12% (0.18 Mtonnes) was recovered/treated (2.4% recycled, 2.6% composted, 6% recovered as energy and 1% treated by other methods) and 82% was disposed of (4.3% incinerated, 78.2% landfilled and 5.5 disposed by other methods). The amount of MSW produced in England was 28.8 million tonnes (Mtonnes), which corresponds to 587 kilograms per inhabitant. The majority of the MSW was landfilled (22 Mtonnes, or 77%), followed by recycling and composting (3.7 Mtonnes, 13%) and 9% of MSW was incinerated (2.6 Mtonnes).

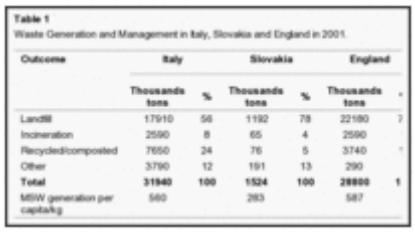

Table 1
Waste Generation and Management in Italy, Slovakia and England in 2001.

Outcome	Italy		Slovakia		England	
	Thousands tons	%	Thousands tons	%	Thousands tons	
Landfill	17910	56	1192	78	22180	
Incineration	2590	8	65	4	2590	
Recycled/composted	7650	24	76	5	3740	
Other	3790	12	191	13	290	
Total	**31940**	**100**	**1524**	**100**	**28800**	**1**
MSW generation per capita/kg	560		283		587	

Table 1

Waste Generation and Management in Italy, Slovakia and England in 2001.

Population living close to incinerators and landfills

Table Table22 shows the characteristics of the populations living close to the incinerators in the three countries. In Italy, more than a million people were included, with 9,010 newborns; less affluent social classes were over-represented compared to the national reference (25% in class V (deprived) and 12.6% in class I (less deprived), where classes are quintiles). A total of 64.4% of residents within 3 km were located in the 2-3 km band zone. Only 16,000 people lived close to the two incinerators in Slovakia. Also in this case, most of the residents lived in the farthest away circle. Contrary to Italy, the social class distribution around the two plants in Slovakia was skewed toward a higher social class. In England, approximately 1,200,000 people lived around the 11 incineration plants, mostly in the 2-3 km circular zone, and the social class distribution was strongly skewed towards deprivation (55% in class V (deprived) versus 3% in class I (less deprived).

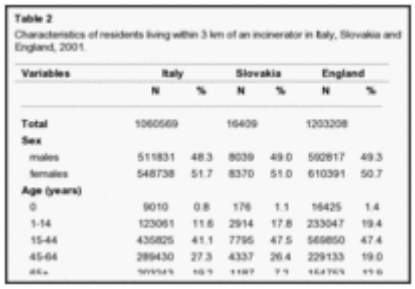

Table 2

Characteristics of residents living within 3 km of an incinerator in Italy, Slovakia and England, 2001.

Variables	Italy		Slovakia		England	
	N	%	N	%	N	%
Total	1060569		16409		1203208	
Sex						
males	511831	48.3	8039	49.0	592817	49.3
females	548738	51.7	8370	51.0	610391	50.7
Age (years)						
0	9010	0.8	176	1.1	16425	1.4
1-14	123061	11.6	2914	17.8	233047	19.4
15-44	435825	41.1	7795	47.5	569850	47.4
45-64	289430	27.3	4337	26.4	229133	19.0

Table22 shows the characteristics of the population living close to landfills in the three countries. The statistics for Italy were calculated for 118 sites in five regions and then extrapolated to the national level that included 619 sites. In Italy, more than 1,350,000 people were included (11,766 newborns); the social class distribution was skewed towards more deprivation (26% in class V (deprived) versus 13% in class I (less deprived)). The majority of residents within 2 km (85.7%) were located in the 1-2 km circular zone. A total of 328,869 people lived close to the 121 landfill plants in Slovakia. Also in this case, most of the residents lived in the longest circle farther away. In England, a total of 1,425,350 people lived close to the 232 geocoded landfills (including 16,242 newborns), especially in the 1-2 km circular area, and the social class distribution was skewed towards deprivation (20% in class V (deprived) versus 2.5% in class I (less deprived)), although the interpretation is difficult for the large proportion of the population with missing data on socioeconomic status.

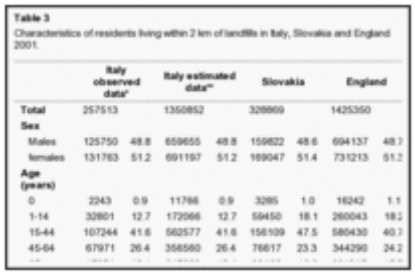

Table 3

Characteristics of residents living within 2 km of landfills in Italy, Slovakia and England 2001.

Table Table44 shows the results of the application of the local air dispersion model. Population-weighted additional exposure to PM_{10} and NO_2 in 2001 is shown together with standard deviation and percentiles. The estimates for Italy and England derive from models with measured emissions (1st method) or national limits (2nd method). The additional contribution to PM_{10} (using the national limit value) is 0.0114 μg/m^3 for Italy, 0.0078 μg/m^3 for Slovakia, and 0.0143 μg/m^3 for England. The additional contribution to NO_2 (using the national limit value) is 0.2271 μg/m^3 for Italy, 0.1542 μg/m^3 for Slovakia, and 0.2855 μg/m^3 for England. The use of measured emission values had a strong impact on the estimate for PM_{10} (eg. 0.0030 μg/m^3 for Italy) but a lower impact for NO_2 (e.g. 0.1944 μg/m^3 for Italy).

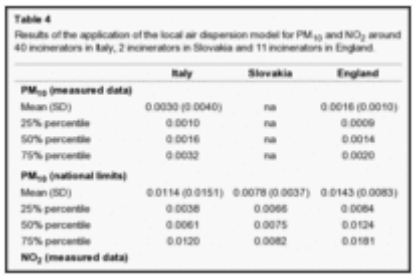

Table 4

Results of the application of the local air dispersion model for PM_{10} and NO_2 around 40 incinerators in Italy, 2 incinerators in Slovakia and 11 incinerators in England.

	Italy	Slovakia	England
PM_{10} (measured data)			
Mean (SD)	0.0030 (0.0040)	na	0.0016 (0.0010)
25% percentile	0.0010	na	0.0009
50% percentile	0.0016	na	0.0014
75% percentile	0.0032	na	0.0020
PM_{10} (national limits)			
Mean (SD)	0.0114 (0.0151)	0.0078 (0.0037)	0.0143 (0.0083)
25% percentile	0.0038	0.0066	0.0084
50% percentile	0.0061	0.0075	0.0124
75% percentile	0.0120	0.0082	0.0181
NO_2 (measured data)			

When PM_{10} and NO_2 population-weighted exposure levels were examined by selected population characteristics, no differences were found for gender and age but higher exposure values were found among those of lower socioeconomic status in Italy and England (not in Slovakia) (data not shown).

Health impacts due to incinerators

Table Table55 shows the estimated number of additional cancer incident cases in the three countries for the period 2001-2050 as a result of exposure before 2001 (past exposure) and during 2001-2020 (current exposure). In Italy, an additional number of approximately 90 cases per year will be attributable to past exposure up to 2020 and then the number will decline to a minimum of 1.6 in 2050. On the other hand, the annual number of cases due to current exposure increases to 11 in 2020 and then will decline to 0 in 2050. In total, 2,729 additional cancer cases will be attributable to incinerators in Italy during 2001-2050 and the vast majority of them will be due to exposure before 2001. The total number of cancers attributable to exposure during 2001-2020 is 189.

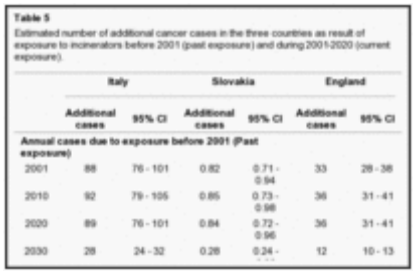

Table 5

Estimated number of additional cancer cases in the three countries as result of exposure to incinerators before 2001 (past exposure) and during 2001-2020 (current exposure).

	Italy		Slovakia		England	
	Additional cases	95% CI	Additional cases	95% CI	Additional cases	95% CI
Annual cases due to exposure before 2001 (Past exposure)						
2001	88	76 - 101	0.82	0.71 - 0.94	33	28 - 38
2010	92	79 - 105	0.85	0.73 - 0.98	36	31 - 41
2020	89	76 - 101	0.84	0.72 - 0.96	36	31 - 41
2030	28	24 - 32	0.28	0.24 -	12	10 - 13

Table 5

Estimated number of additional cancer cases in the three countries as result of exposure to incinerators before 2001 (past exposure) and during 2001-2020 (current exposure).

In Slovakia, less than one additional case per year is estimated for past exposure during the whole period whereas the estimate for current exposure is very low. In total, 24 additional cancer cases will be attributable to incinerators in Slovakia during 2001-2050 and the majority of them will be due to exposure before 2001. The total number of cancers attributable to exposure during 2001-2020 is 1.2.

In England, an additional number of approximately 36 cases per year will be attributable to past exposure up to 2020 and then the number will decline to 0 in 2050. On the other hand, the annual number of cases due to current exposure increases to 7 in 2020 and then will decline to 0 in 2050. In total, 1,125 additional cancer cases will be attributable to incinerators in England during 2001-2050 and the vast majority of them will be due to exposure before 2001. The total number of cancers attributable to exposure during 2001-2020 is 120.

Table Table66 shows the total number of Years of Life Lost, YoLL (also the YoLL per 100,000 inhabitants and the number of lost days per person) in the three countries attributable to exposure to PM_{10} or NO_2 from incinerators. In Italy, the impact is higher for NO_2 (total YoLL 3,621, 341.4 per 100,000 inhabitants) than for PM_{10} (total YoLL 181, 17.16 per 100,000 inhabitants). In Slovakia, the total number of YoLL is also higher for NO_2 (37, 226 per 100,000) than for PM_{10} (2, 12.2 per 100,000). Comparable results were available for England with a total impact similar to Italy (for NO_2: total YoLL 3,966, 330 per 100,000 inhabitants; for PM_{10}: total YoLL 199, 16.5 per 100,000 inhabitants). Overall, the maximum impact of incinerators is 1.25 days per each person in Italy, 0.82 days per person in Slovakia, and 1.20 days per person in England.

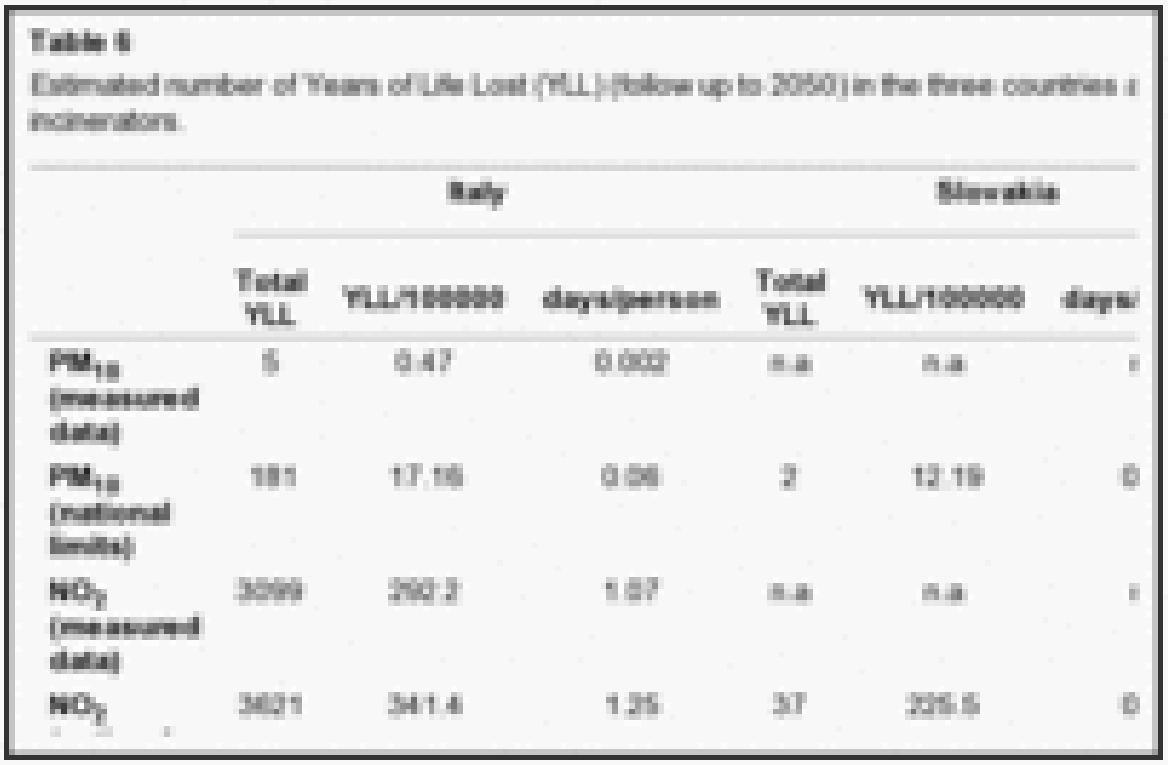

Table 6

Estimated number of Years of Life Lost (YLL) (follow up to 2050) in the three countries a incinerators.

	Italy			Slovakia		
	Total YLL	YLL/100000	days/person	Total YLL	YLL/100000	days/
PM_{10} (measured data)	5	0.47	0.002	n.a	n.a	
PM_{10} (national limits)	181	17.16	0.06	2	12.19	0
NO_2 (measured data)	3099	292.3	1.07	n.a	n.a	
NO_2	3821	361.4	1.35	37	226.5	0

[Table 6]

Estimated number of Years of Life Lost (YLL) (follow up to 2050) in the three countries as result of exposure to PM_{10} and NO_2 from incinerators.

Health impacts due to landfills

Table [Table77] shows the health effects of landfills in the three countries as annual cases of congenital malformations and newborns of low birth weight during the period 2001-2030. It is expected that an average of 1.96 (95%CI = 0.98-2.94) additional cases of birth defects per year occur in Italy, 1.54 (0.77-2.31) in Slovakia and 2.7 (1.35-4.0) in England. The estimated number of infants of low birth weight is 42 (95%CI = 35-42), 13 (11-13), and 58 (49-58) cases per year for 30 years, respectively for the three countries.

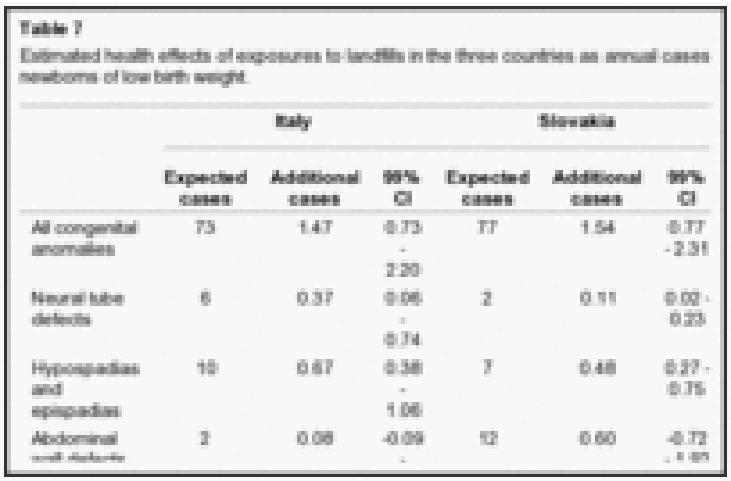

Table 7

Estimated health effects of exposures to landfills in the three countries as annual cases newborns of low birth weight.

	Italy			Slovakia		
	Expected cases	Additional cases	95% CI	Expected cases	Additional cases	95% CI
All congenital anomalies	73	1.47	0.73 - 2.20	77	1.54	0.77 - 2.31
Neural tube defects	6	0.37	0.06 - 0.74	2	0.11	0.02 - 0.23
Hypospadias and epispadias	10	0.67	0.38 - 1.06	7	0.48	0.27 - 0.75
Abdominal	2	0.08	-0.09 -	12	0.60	-0.72 -

Table 7

Estimated health effects of exposures to landfills in the three countries as annual cases of congenital malformations and newborns of low birth weight.

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Discussion

We found that the three countries differed with regard to recycling, landfilling and incineration policies: in Slovakia and England landfills were the most important method of management whereas Italy had a higher proportion of recycling and use of mechanical and biological treatment (MBT) technologies; incineration was used equally in Italy and England. There was a sizeable population living close to management plants in the three areas (e.g. approximately 2% of the entire population in Italy live close to an incinerator while an additional 2.5% live close to a landfill). In both Italy and England, populations of lower socio-economic status were more likely to live closer to waste disposal sites.

A systematic review of the scientific literature [4] revealed that cancer incidence and adverse reproductive outcomes (congenital malformations and low birth weight) are the main health effects possibly related to incinerators and landfills, respectively. On the basis of the relative risks derived from published data, we found that the largest health impact from incinerators during the period of evaluation (2001-2050) was cancer incidence accounting for a small percentage increase over the background in the exposed population. The majority of the cancer cases are due to exposures occurring before 2001 whereas the relative impact from the current exposure pattern is smaller. The health burden is thus not amenable to intervention from new policies since those cancer cases will occur in any case. On the other hand, policies for future developments should consider that most of the health effects will be seen over several decades.

Confirming preliminary research in the UK [27], the additional contribution to the PM_{10} and NO_2 background in proximity of incinerators estimated with air dispersion models is relatively small and roughly equivalent in the three countries. The application of the air dispersion model data to a life table analysis indicates that the maximum impact of incinerators on the overall mortality of the resident cohort will be from exposure to NO_2. A few hundred Years of Life Lost per 100,000 people over the period 2001-2020 are expected to occur and the results are consistent in the three countries. However, the burden estimated with a large scale model for the entire European population should be added to the overall impact of incineration as the impact is widespread.

Our evaluation of the impact of landfills is driven from the relative lack of scientific knowledge related to health effects since only adverse reproductive disorders were considered. The studies reviewed and used for impact assessment are based on distance from the sources and they do not provide indication of the relevant etiological exposures. For incinerators, there was a variety of emissions from the stacks of these plants, including

particles and gases, Polycyclic Aromatic Hydrocarbons, heavy metals and dioxins for which a link with cancer can be easily justified. On the other hand, a biological explanation for the health impacts from landfills is more difficult since the causative agents (e.g. heavy metals, Polycyclic Aromatic Hydrocarbons, solvents) and the exposure routes (inhalation, ingestion of drinking water, contact with contaminated soil) for reproductive outcomes have not been indicated. Without identifying the causative agent/s and a plausible mechanism of effect and exposure, the level of confidence of the health impact assessment is moderate. Overall, the overall estimated burden in each country consists of few cases of congenital malformations and low birth weight newborns.

There are several examples in the literature of risk assessment of a single or a limited number of waste management plants [27]. Results of risk assessment performed at the country level are more limited, although the ExternE methodology [28,29] has been applied to estimate external costs of waste management. Rabl et al. [29] concluded that the only significant contributions come from direct emissions (of the landfill or incinerator) and from avoided emissions due to energy recovery (from an incinerator). Damage costs for incineration range from about 4 to 21 EUR tonne waste, and they are extremely dependent on the assumed scenario for energy recovery. For landfills the costs range from about 10 to 13 EUR tonne waste; it is dominated by greenhouse gas emissions because only a fraction of the CH4 can be captured. A complete assessment has been conducted in Singapore [30] but the main focus was on the environmental impact. Experiences of the health impact assessment in Europe are available from Ireland [31] and England [32]. The latest study provides a wide-ranging review focused on the environmental and health effects of MSW management.

Since lower socio-economic status is already associated with a higher risk of various negative health outcomes, an issue of environmental justice is present here because of the higher probability of exposure for less affluent people and their increased vulnerability. The situation is different for the two incinerators in Slovakia since they have an urban location and people living in urban areas in that country tend to have a higher socioeconomic profile. The issue has been extensively discussed in a recent paper [33] concluding that more effort should be made to investigate whether disadvantaged people are more vulnerable, i.e. risks differ in different social groups living in the same area. Notwithstanding this open question, decision makers should identify waste management policies that minimize their potential health impacts and unequal distribution.

Limitations and uncertainties

In our study, we assessed the potential impact of incinerators and landfill sites on the health of the nearby population. However, there are some key choices and limitations that are important to consider. There are substantial environmental emissions associated with waste transport that we did not consider in the present assessment. In addition, it was outside the scope of the present study to consider the potential health effects of composting and of mechanical and biological plants, the two main alternatives to incineration and landfilling [3]. Finally, we did not take into account the potential occupational health risks to waste management workers, in particular occupational accidents.

Our health impact assessment is characterized by a number of uncertainties that are typical of these exercises focusing on the long term-effects of prolonged, low-level exposures. We have listed the sources of uncertainties for each step of our evaluation and briefly summarize our

confidence in the methods and results. The direction of the bias generated by these uncertainties is unknown.

Waste generation and management

As expected, there were inadequacies in data availability and reliability on MSW indicators as they are not uniform and not always available in the same format from published statistics. There were approximations in the available information on waste composition, classification of wastes is different in different countries, and we had high uncertainty concerning the amount and treatment of illegally disposed of waste. Overall, however, we have high confidence in the summary statistics that we have used and reported as they were available from reliable sources.

Population characteristics and exposure to air pollutants

While we had relatively high quality data for incinerators in the three countries, exact coordinates of landfills were difficult to find in Italy. In addition, we did face difficulties in estimating the exposed population because the location of the plant was approximate, the size of some landfills is not known, and the unit of the available population data (census block) does not fit our needs. Population data by age and gender, available locally, are based on census and projections for years beyond the census. Overall, we have very high confidence in the population data close to incinerators but our confidence in population data close to landfills is only moderate.

The results of the air dispersion models depend on the quality of the input data. We had operational data measured during recent years for some of the incinerators but only estimated emissions for some others. In addition, some plant characteristics were missing and had to be imputed. On the other hand, we could rely on high quality meteorological data for most of the plants and topography was also considered. Overall, we have a moderate confidence in the estimated air pollution concentrations close to incineration plants.

Relative risks and exposure-response functions

The application of excess-risk estimates based on distance from the plants has been problematic because of several difficulties in interpreting epidemiological studies. We have tried to address the issue in a transparent way by conducting a systematic evaluation, however, as underlined on several occasions above, we have moderate confidence in the excess risks used for the impact assessment of cancer cases and adverse reproductive outcomes. On the other hand, we have high confidence in the coefficients for long-term effects of PM_{10} and NO_2 on mortality.

Quantification of the health impact

The quantification has been straightforward in terms of calculating excess cases as there are no difficulties in finding the appropriate health statistics and in taking into account the particular population characteristics near the facilities. However, the most difficult part is attributing the effect studied from old plants using old technologies to new facilities. We tried to evaluate the consequence of changing some of the parameters. Overall, we have moderate confidence in our method to estimate excess cancer cases and reproductive outcomes. On the other hand, we think the life table approach is rather robust, despite the assumptions made

(time of the effect, stability of the population, constant mortality). Finally, there may be more health effects of living near waste facilities that were not considered for lack of suitable evidence. For example, a general loss of quality of life, stress, odours, poor perceived health, besides being important health endpoints per se, may also contribute to increases in morbidity and mortality. For all of these reasons, we have a moderate level of confidence in our quantification of the health impacts.

Our approach to evaluate the level of confidence deserves discussion. Explicitly addressing uncertainty is an important contribution of research because it clarifies what is known and unknown and thus stimulates further investigation. We rated the confidence we had according to a scheme adapted from the one used by the IPCC. The approach has been recently used to address the health impact of ultrafine particles in an expert elicitation process [34]. In this case, the likelihood of an effect of ultrafine particles on natural mortality was considered as moderate whereas the likelihood of and effect on asthma aggravation was considered vey high.

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Conclusions

Past exposures from incinerators were likely to cause a sizeable health impact, especially for cancer, in Italy and England. However, the current impacts of landfilling and incineration can be characterized as moderate when compared to other sources of environmental pollution, e.g. traffic or industrial emissions, that have an importance on public health. The main results of the present study should be viewed in relation to the present debate within the EU and the Member States on the main policy issues related to waste management. Questions remain on the efforts that individual countries should make to reduce the overall amount of waste, and the appropriate targets to be met for recycling. Although waste to energy is gradually replacing old mass incineration, open issues remain also over the extent to which such policies should be introduced, given the possible alternatives [3]. There are several uncertainties and critical assumptions in our assessment model that are typical of a complex problem. However, we believe that it provides some insight into the relative health impact attributable to waste incineration and landfilling and that the model could potentially be useful as part of more articulated assessments for evaluating waste policy options, identifying knowledge gaps, and providing a framework for future comparative risk assessment.

Go to:

List of abbreviations

EU: European Union; INTARESE: Integrated Assessment of Health Risks of Environmental Stressors in Europe; IPCC: Intergovernmental Panel on Climate Change; UK: United Kingdom; PM10: Particulate Matter; NO2: Nitrogen Dioxide; GIS: Geographic Information System; CH4: Methane.

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Competing interests

The authors declare that they have no competing interests.

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Authors' contributions

FF conceived of and designed the study, participated in the statistical analysis and drafted the manuscript. CB dealt with the GIS system and with exposure assessment. KdH performed the dispersion models, participated in the design of the study and drafted the manuscript. MKvK participated in the study conception, design, and uncertainty assessment. MM participated in the study conception and design. FM participated in the study conception and design. LP participated in the design of the study and collected environmental data. DP participated in the design of the study, to statistical analysis and drafted the manuscript. PP participated in the study conception and design. AR participated in the design of the study and collected environmental data. CAP participated in the study conception and design. DB was involved in coordination and interpretation. All authors have read and approved the final manuscript.

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Supplementary Material

Additional file 1:

"Estimating attributable cancer incidence around incinerators". rationale, methods, calculation and sensitivity analysis for the estimates of the attributable cancer cases around incinerators.

Click here for file (794K, DOC)

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Acknowledgements

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