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Cancer mortality in towns in the vicinity of incinerators and installations for the recovery or disposal of hazardous waste

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ABSTRACT

Background: Waste treatment plants release toxic emissions into the environment which affect neighboring towns.
Objectives: To investigate whether there might be excess cancer mortality in towns situated in the vicinity of Spanish-based incinerators and installations for the recovery or disposal of hazardous waste, according to the different categories of industrial activity.
Methods: An ecologic study was designed to examine municipal mortality due to 33 types of cancer, across the period 1997–2006. Population exposure to pollution was estimated on the basis of distance from town of residence to pollution source. Using Besag–York–Mollié (BYM) regression models with Integrated Nested Laplace approximations for Bayesian inference, and Mixed Poisson regression models, we assessed the risk of dying from cancer in a 5-kilometer zone around installations, analyzed the effect of category of industrial activity, and conducted individual analyses within a 50-kilometer radius of each installation.
Results: Excess cancer mortality (BYM model: relative risk, 95% credible interval) was detected in the total population residing in the vicinity of these installations as a whole (1.06, 1.04–1.09), and, principally, in the vicinity of incinerators (1.09, 1.01–1.18) and scrap metal/end-of-life vehicle handling facilities, in particular (1.04, 1.00–1.09). Special mention should be made of the results for tumors of the pleura (1.71, 1.34–2.14), stomach (1.18, 1.10–1.27), liver (1.18, 1.06–1.30), kidney (1.14, 1.04–1.23), ovary (1.14, 1.05–1.23), lung (1.10, 1.05–1.15), leukemia (1.10, 1.03–1.17), colon–rectum (1.08, 1.03–1.13) and bladder (1.08, 1.01–1.16) in the vicinity of all such installations.
Conclusions: Our results support the hypothesis of a statistically significant increase in the risk of dying from cancer in towns near incinerators and installations for the recovery or disposal of hazardous waste.

1. Introduction

Generation of waste by human activity is a matter of worldwide concern. Municipal incinerators and installations for the recovery or disposal of hazardous waste help address this problem but inevitably generate and release toxic emissions and effluents, such as dioxins – carcinogens recognized by the International Agency for Research on Cancer (IARC) (IARC, 1997) – into the environment, which then affect neighboring towns,.

Some studies have linked exposure to incinerator emissions, with adverse reproductive outcomes (Dummer et al., 2003), respiratory problems (Miyake et al., 2005) and cancer (Comba et al., 2003; Knox, 2000; Viel et al., 2008). With respect to treatment (elimination, disposal or recovery) of hazardous waste, which includes activities such as the recycling of scrap metal and end-of life vehicles (ELVs), re-refining of used oil, and physico/chemical treatment of waste, there are hardly any epidemiologic studies on these installations' health effects on the populations of nearby towns, even though they are known to release carcinogens, such as dioxins, arsenic, benzene, cadmium and chromium (Environmental Protection Agency, 2002; Landrigan et al., 1989). Accordingly, it would seem appropriate to ascertain whether residential proximity to these little-studied types of pollutant facilities might have an influence on the frequency of cancer.

Abbreviations: IARC, Agency for Research on Cancer; ELVs, End-of life vehicles; IPPC, Integrated Pollution Prevention and Control; E-PRTR, European Pollutant Release and Transfer Register; NSI, National Statistics Institute; PCBs, Polychlorinated biphenyls; RRs, Relative risks; 95% CrIs/CIs, 95% credible/confidence intervals; BYM, Besag, York and Mollié; INLAs, Integrated nested Laplace approximations; PAHs, Polycyclic aromatic hydrocarbons; NHL, Non-Hodgkin's lymphoma.

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In the case of pollution sources in Spain, the European Commission directives passed in 2002 afforded a new means of studying the consequences of industrial pollution: Integrated Pollution Prevention and Control (IPPC), governed both by Directive 96/61/CE (recently codified into Directive 2008/1/EC) and by Act 16/2002, which incorporates this Directive into the Spanish legal system, lays down that, to be able operate, industries covered by the regulation must obtain the Integrated Environmental Permit. This same enactment implemented the European Pollutant Release and Transfer Register (E-PRTR) in 2007, which makes it compulsory to declare all pollutant emissions to air, water and soil, that exceed the designated thresholds, and contains detailed information about the address and type of industrial activity in which the installations are involved. IPPC and E-PRTR records thus constitute an inventory of geo-located industries with environmental impact in Europe, which is a valuable resource for monitoring industrial pollution and, by extension, renders it possible for the association between residential proximity to such pollutant installations and health impacts, such as cancer, to be studied (Garcia-Perez et al., 2012; Lopez-Abente et al., 2012; Lopez-Cima et al., 2011).

In this context, this study sought to: (1) assess possible excess mortality attributable to 33 tumor sites among the Spanish population residing in the environs of incinerators and hazardous waste treatment plants governed by the IPPC Directive and E-PRTR Regulation; (2) analyze this risk according to the different categories of industrial activity, and for each installation individually; and, (3) perform the analysis for the population, both overall and broken down by sex, using different statistical approaches for the purpose.

2. Materials and methods

We designed an ecologic study to evaluate the association between cancer mortality and proximity to incinerators and hazardous waste treatment plants at a municipal level (8098 Spanish towns), during the period 1997–2006. Separate analyses were performed for the overall population and for each sex.

2.1. Mortality data

Observed municipal mortality data were drawn from the records of the National Statistics Institute (NSI) for the study period, and corresponded to deaths due to 33 types of malignant tumors (see Supplementary data, Table 1, which shows the list of tumors analyzed and their codes as per the International Classification of Diseases—9th and 10th Revisions). Expected cases were calculated by taking the specific rates for Spain as a whole, broken down by age group (18 groups: 0–4, …, 80–84 years, and 85 years and over), sex, and five-year period (1997–2001, 2002–2006), and multiplying these by the person-years for each town, broken down by the same strata. Person-years for each quinquennium were calculated by multiplying the respective populations by 5 (with data corresponding to 1999 and 2004 being taken as the estimator of the population at the midpoint of the study period). In addition, we specifically analyzed leukemias and brain cancer in subjects under ages 15 and 25 years, since these were the most frequent tumors in adolescents and young adults in our data.

2.2. Industrial pollution exposure data

Population exposure to industrial pollution was estimated by taking the distance from the centroid of town of residence to the industrial facility. We used the industrial database (industries governed by IPPC and facilities pertaining to industrial activities not subject to IPPC but included in the E-PRTR) provided by the Spanish Ministry for Agriculture, Food & Environment in 2007. Bearing in mind the minimum induction periods for the tumors targeted for study, generally 10 years for solid tumors and 1 year for leukemias (United Nations Scientific Committee on the Effects of Atomic Radiation, 2006), two industry databases were used:

a) for the study of leukemias, we selected the 129 installations corresponding to IPPC categories 5.1 (installations for the recovery or disposal of hazardous waste with a capacity exceeding 10 t per day) and 5.2 (installations for the incineration of municipal waste with a capacity exceeding 3 t per hour), which came into operation prior to 2002 (1 year before the mid-year of the study period), denominated "pre-2002 installations"; and,
b) for the remaining tumors, we selected the 67 installations corresponding to IPPC categories 5.1 and 5.2 which came into operation prior to 1993 (10 years before the mid-year of the study period), denominated "pre-1993 installations".

The date (year) of commencement of the respective industrial activities was provided by the industries themselves.

Each of the installations was classified into one of the following 9 categories of industrial activities, according to the type of waste involved and treatment applied:

1. "*Incineration*": incineration of solid urban (municipal) and special waste (9 pre-2002 and 5 pre-1993 installations);
2. "*Scrap metal + ELVs*": scrapping/decontamination of ELVs, and recycling of scrap metal (ferrous and non-ferrous products) and electric/electronic equipment (32 pre-2002 and 23 pre-1993 installations);
3. "*Oils + Oily waste*": treatment of used oil, oily marine pollutant (MARPOL) waste and decontamination of equipment contaminated by polychlorinated biphenyls (PCBs) (24 pre-2002 and 8 pre-1993 installations);
4. "*Packaging*": recycling of metallic and plastic industrial packaging (9 pre-2002 and 5 pre-1993 installations);
5. "*Solvents*": recovery of used solvents (7 pre-2002 and 5 pre-1993 installations);
6. "*Spent baths*": regeneration of spent acid pickling and basic baths and hydrochloric acid used in metal descaling (7 pre-2002 and 5 pre-1993 installations);
7. "*Physico/chemical treatment*": physico/chemical treatment of waste not included in the above sections (8 pre-2002 and 4 pre-1993 installations);
8. "*Industrial waste*": treatment of industrial waste not included in the above sections, such as recovery of wastes from the iron and steel industry (15 pre-2002 and 7 pre-1993 installations); and,
9. "*Wastes not otherwise specified*": treatment of waste not included in any of the above sections, such as medical wastes, lead acid batteries, photochemical wastes, or textile wastes (18 pre-2002 and 5 pre-1993 installations). This category also included installations that treated different types of waste or applied several different treatment processes.

Owing to the presence of errors in the initial location of industries, the geographic coordinates of the industrial locations recorded in the IPPC + E-PRTR 2007 database were previously validated: every single address was thoroughly checked using Google Earth (with the street-view application), the Spanish Agricultural Plots Geographic Information System (which includes orthophotos and topographic maps showing the names of the industries) (Ministerio de Agricultura Alimentación y Medio Ambiente, 2012), the Google Maps server and the "Yellow pages" web page (which allow for a search of addresses and companies), and the web pages of the industries themselves, to ensure that location of the industrial facility was exactly where it should be. 25% of the incinerators and hazardous waste treatment installation coordinates were corrected at a distance of 4471 m or more from the original location in the IPPC + E-PRTR database.

2.3. Statistical analysis

Three types of analysis were performed to assess possible excess cancer mortality in towns lying near ("near") versus those lying far ("far") from incinerators and hazardous waste treatment installations, known as a "near vs. far" analysis. In all cases, a distance of 5 km was taken as the area of proximity ("exposure") to industrial installations, in line with the distance used by other studies on these types of installations (Federico et al., 2010; Knox, 2000; Leem et al., 2006):

1) in a first phase, we conducted a "near vs. far" analysis to estimate the relative risks (RRs) of towns situated at a distance of ≤5 km from incinerators and hazardous waste treatment installations as a whole. The variable, "exposure", was coded as: a) exposed or proximity area ("near"), consisting of towns lying at a distance of ≤5 km from any incinerator or hazardous waste treatment facility; b) intermediate area, consisting of towns lying at a distance of ≤5 km from any industrial installation other than incinerators or hazardous waste treatment facilities; and, c) unexposed area ("far"), consisting of towns having no (IPPC + E-PRTR)-registered industry within 5 km of their municipal centroid (reference group);
2) in a second analysis, we decided to stratify risk of analysis anterior according to the different categories of industrial activity. To this end, we created a variable of "exposure" in which the exposed area was stratified into the following groups: Group 1, made up of towns lying close (≤5 km) to one or more installations belonging to the category "Incineration"; Group 2, if the category was "Scrap metal + ELVs", and so on, until Group 9, if the category was "Wastes not otherwise specified"; and Group 10, made up of towns lying close to two or more installations belonging to different categories of activity ("multiple pollutant categories"). Intermediate and unexposed areas were defined as in the preceding phase; and,
3) lastly, bearing in mind that characteristics tend to vary from one incinerator or hazardous waste treatment facility to the next, we conducted separate "near vs. far" analyses of the individual installations, with the analysis being confined to an area of 50 km surrounding each such installation so as to have a local comparison group.

For all the above analyses, we used two statistical approaches based on log-linear models to estimate the RRs and their 95% credible/confidence intervals (95% CrIs/CIs), assuming that the number of deaths per stratum followed a Poisson distribution:

a) a Bayesian conditional autoregressive model proposed by Besag, York and Mollié (BYM) (Besag et al., 1991), with explanatory variables:

$$O_i \sim Poisson(\mu_i), \text{with} \mu_i = E_i \lambda_i$$

$$\log(\lambda_i) = \alpha Expos_i + \sum_j \beta_j Soc_{ij} + h_i + b_i \Rightarrow \log(\mu_i) = \log(E_i) + \alpha Expos_i + \sum_j \beta_j Soc_{ij} + h_i + b_i$$

$$Soc_{ij} = ps_i + ill_i + far_i + unem_i + pph_i + inc_i$$

$$i = 1, \ldots, 8098 \ \ towns, \quad j = 1, \ldots, 6 \ \ potential \ confounders$$

$$h_i \sim Normal(\theta, \tau_h)$$
$$b_i \sim Car.Normal(\eta_i, \tau_b)$$
$$\tau_h \sim Gamma(\alpha, \beta)$$
$$\tau_b \sim Gamma(\gamma, \delta)$$

b) a mixed Poisson regression model (Gelman and Hill, 2007):

$$O_i \sim Poisson(\mu_i), \text{with} \mu_i = E_i \lambda_i$$

$$\log(\lambda_i) = \alpha Expos_i + \sum_j \beta_j Soc_{ij} + p_i \Rightarrow \log(\mu_i) = \log(E_i) + \alpha Expos_i + \sum_j \beta_j Soc_{ij} + p_i$$

$$Soc_{ij} = ps_i + ill_i + far_i + unem_i + pph_i + inc_i$$

$$i = 1, \ldots, 8098 \ \ towns, \quad j = 1, \ldots, 6 \ \ potential \ confounders$$

with λ_i being the RR in town i, the number of observed deaths in town i for each cancer site (O_i) being the dependent variable, and the number of expected deaths in town i for each cancer site (E_i) being the offset, in both cases. All estimates for the variable of "exposure" ($Expos_i$) were adjusted for the following standardized, sociodemographic indicators (Soc_{ij}), chosen as potential confounders directly from the 1991 census for their availability at a municipal level and potential explanatory ability vis-à-vis certain geographic mortality patterns (Lopez-Abente et al., 2006): population size (ps_i) (categorized into three levels: 0–2000, 2000–10,000 and ≥10,000 inhabitants); percentage illiteracy (ill_i), farmers (far_i) and unemployed ($unem_i$); average persons per household (pph_i); and mean income (inc_i) by the Spanish Market Yearbook, as a measure of income level (Ayuso Orejana et al., 1993). Their geographic patterns show the economic, demographic and social development of Spain, appreciating some spatial correspondence between illiteracy, unemployment and younger population areas. The variable of "exposure" and potential confounding covariates were fixed-effects terms in the models.

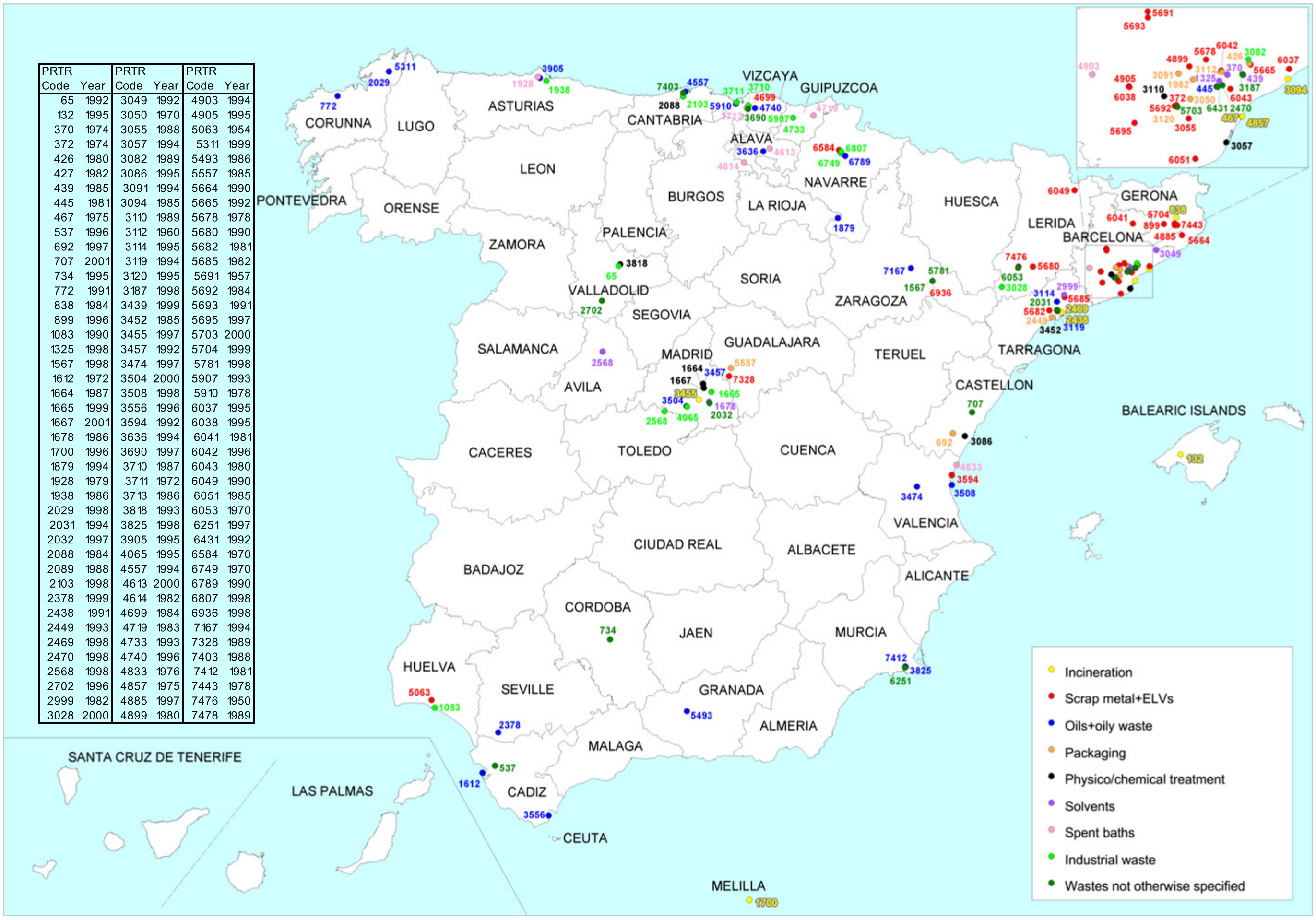
To enable the spatial autocorrelation problem (presence of geographic patterns in contiguous spatial data) to be assessed, this was estimated by applying Moran's I statistic to the Standardized Mortality Ratios (Bivand et al., 2008). The BYM Bayesian autoregressive model takes this problem into account, thanks to the inclusion of two random effects components, namely: a spatial term containing municipal contiguities (b_i); and the municipal heterogeneity term (h_i). Integrated nested Laplace approximations (INLAs) (Rue et al., 2009) were used as a tool for Bayesian inference. For this purpose, we used R-INLA (The R-INLA project, 2012), with the option of simplified Laplace estimation of the parameters. A total of 8098 towns were included, and the spatial data on municipal contiguities were obtained by processing the official NSI maps.

Furthermore, the mixed Poisson regression model includes province as a random effects term (p_i), to enable geographic variability and extra-Poisson dispersion to be taken into account and unexposed towns belonging to the same province to be considered as the reference group in each case, something that is justified by the geographic differences observed in mortality attributable to some tumors (Lopez-Abente et al., 2006).

Lastly, a residual analysis (based on deviance residuals) was performed to test the models.

3. Results

Fig. 1 depicts the geographic distribution of the 129 installations studied according to the different categories of industrial activity, together with their PRTR codes and year of commencement of operations. Supplementary data, Table 2 gives a detailed description of the type of activity undertaken by each installation and the pollutants emitted during the preceding decade. In all, the 129 installations released 525,428 t of toxic substances to air and 4984 t to water in 2007, including carcinogens such as arsenic (32 kg to air and 33 kg to water), chromium (81 kg to air and 80 kg to water) and polycyclic aromatic hydrocarbons (PAHs) (48 kg to air and 126 kg to water). More detailed information on emission amounts is provided in Supplementary data, Tables 3 and 4, which show the types of substances and amounts released by these installations to air and water, respectively.



PRTR Code	Year	PRTR Code	Year	PRTR Code	Year
65	1992	3049	1992	4903	1994
132	1995	3050	1970	4905	1995
370	1974	3055	1988	5063	1954
372	1974	3057	1994	5311	1999
426	1980	3082	1989	5493	1986
427	1982	3086	1995	5557	1985
439	1985	3091	1994	5664	1990
445	1981	3094	1985	5665	1992
467	1975	3110	1989	5678	1978
537	1996	3112	1960	5680	1990
692	1997	3114	1995	5682	1981
707	2001	3119	1994	5685	1982
734	1995	3120	1995	5691	1957
772	1991	3187	1998	5692	1984
838	1984	3439	1999	5693	1991
899	1996	3452	1985	5695	1997
1083	1990	3455	1997	5703	2000
1325	1998	3457	1992	5704	1999
1567	1998	3474	1997	5781	1998
1612	1972	3504	2000	5907	1993
1664	1987	3508	1998	5910	1978
1665	1999	3556	1996	6037	1995
1667	2001	3594	1992	6038	1995
1678	1986	3636	1994	6041	1981
1700	1996	3690	1997	6042	1996
1879	1994	3710	1987	6043	1980
1928	1979	3711	1972	6049	1990
1938	1986	3713	1986	6051	1985
2029	1998	3818	1993	6053	1970
2031	1994	3825	1998	6251	1997
2032	1997	3905	1995	6431	1992
2088	1984	4065	1995	6584	1970
2089	1988	4557	1994	6749	1970
2103	1998	4613	2000	6789	1990
2378	1999	4614	1982	6807	1998
2438	1991	4699	1984	6936	1998
2449	1993	4719	1983	7167	1994
2469	1998	4733	1993	7328	1989
2470	1998	4740	1996	7403	1988
2568	1998	4833	1976	7412	1981
2702	1996	4857	1975	7443	1978
2999	1982	4885	1997	7476	1950
3028	2000	4899	1980	7478	1989

Fig. 1. Geographic distribution of Spanish-based incinerators and hazardous waste treatment installations.

Table 1 shows the RRs and 95% CrIs/CIs for cancers proving to be statistically significant in towns situated at ≤5 km from incinerators and hazardous waste treatment installations, estimated using BYM and Poisson mixed regression models and Moran's I test for spatial autocorrelation. Overall, excess cancer mortality was present in both sexes, with the two models displaying identical RRs, which were higher in men (RR = 1.08) than in women (RR = 1.03). In the case of specific tumors, the estimates yielded by both models were largely similar in general (slightly higher and significant in the mixed model in tumors of the oral cavity and pharynx, esophagus and non-Hodgkin's lymphoma (NHL), and somewhat higher in the BYM model in renal cancer). Some cancers – such as all cancers combined (in men and women) or malignant tumors of the stomach (in men and women) and lung, bladder, oral cavity and pharynx, colon–rectum, and liver (in men) – displayed a statistically significant spatial autocorrelation, and it thus seemed appropriate to use the BYM model in order to take this spatial autocorrelation into account. Based on this model, statistically significant RRs appeared for tumors of the stomach, liver, pleura and kidney (in men and women), colon–rectum, lung, bladder, gallbladder and leukemia (in men), and brain and ovary (in women). In these results, note should be taken of the high excess risk for cancer of the pleura (RR = 1.84 in men and RR = 1.52 in women). With respect to leukemias and brain cancer in the under-15- and under-25 age groups, statistically significant excess risks were not in evidence (see Supplementary data, Table 5, which shows the RR of dying from leukemia and brain cancer among the under-15 and under-25 age groups in towns situated at ≤5 km from incinerators and hazardous waste treatment installations, estimated using BYM models).

The analyses of the above table, including the two regression models and spatial autocorrelation test, were performed separately for each tumor (see Supplementary data, Tables 6 and 7, which show the RR of dying from cancer in towns situated at ≤5 km from incinerators and hazardous waste treatment installations as a whole – estimated using BYM models – and Moran's I *p*-values for spatial autocorrelation analyses, respectively). In the residual analysis of the BYM model for all tumors under study, the graphs plotting deviance residuals against distance to the nearest installation displayed an apparently random scatter pattern, consistent with a well-fitted model (see Supplementary data, Fig. 1).

Table 2 shows the RRs and 95% CrIs estimated with BYM models for cancers that yielded statistically significant results in the analysis of risk stratified by category of industrial activity. For all cancers combined, statistically significant excess risks were observed in the environs of multiple pollutant categories (men and women), incinerators and installations for the recycling of scrap metal + ELVs (total population), and installations for the regeneration of spent baths (men), though in no case were these higher than 10%. Insofar as the remaining tumors were concerned, attention should be drawn to the significant excess risks found for the following (we have highlighted the highest statistically significant RRs for each tumor): stomach and colorectal cancers in men, in the vicinity of packaging recycling industries (RRs = 1.53 and 1.29, respectively); cancers of the liver and ovary in women, in

Table 1
Relative risk of dying from cancers with significant results in towns situated at ≤5 km from incinerators and hazardous waste treatment installations as a whole, estimated using BYM and Poisson mixed regression models, and Moran's I test for spatial autocorrelation. Significant results are in bold.

	T[a]	Obs[b]	Exp[c]	BYM model		Mixed model		Moran's I test
				RR[d]	95%CrI[e]	RR[d]	95%CI[f]	*p*-Value
All cancers[g]								
Total	163	91,708	85,109.6	**1.06**	**1.04–1.09**	**1.06**	**1.05–1.07**	**0.0001**
Men	163	58,275	53,071.8	**1.08**	**1.05–1.11**	**1.08**	**1.07–1.10**	**0.0001**
Women	163	33,433	32,037.8	**1.03**	**1.01–1.06**	**1.03**	**1.01–1.04**	**0.0006**
Oral and pharyngeal cancer								
Total	163	2482	2178.7	1.04	0.95–1.14	**1.11**	**1.05–1.19**	**0.0039**
Men	163	2056	1804.5	1.03	0.94–1.13	**1.11**	**1.04–1.19**	**0.0031**
Women	163	426	374.2	1.09	0.94–1.26	1.07	0.93–1.24	0.4660
Esophageal cancer								
Total	163	1960	1733.3	0.99	0.90–1.09	**1.07**	**1.00–1.15**	0.0725
Men	163	1710	1504.0	1.01	0.91–1.11	**1.08**	**1.00–1.16**	0.0979
Women	163	250	229.4	0.92	0.74–1.13	1.02	0.84–1.24	0.7441
Stomach cancer								
Total	163	6123	5646.0	**1.18**	**1.10–1.27**	**1.07**	**1.03–1.11**	**0.0001**
Men	163	3822	3461.8	**1.18**	**1.09–1.28**	**1.09**	**1.04–1.15**	**0.0073**
Women	163	2301	2184.3	**1.16**	**1.06–1.27**	1.04	0.98–1.11	**0.0049**
Colorectal cancer								
Total	163	12,265	11367.2	**1.08**	**1.03–1.13**	**1.06**	**1.03–1.09**	**0.0004**
Men	163	7084	6343.6	**1.12**	**1.06–1.18**	**1.08**	**1.04–1.12**	**0.0131**
Women	163	5181	5023.6	1.04	0.98–1.10	1.03	0.99–1.08	0.6319
Liver cancer								
Total	163	2929	2310.4	**1.18**	**1.06–1.30**	**1.23**	**1.15–1.31**	**0.0012**
Men	163	2075	1678.6	**1.17**	**1.05–1.30**	**1.22**	**1.13–1.31**	**0.0014**
Women	163	854	631.8	**1.20**	**1.02–1.40**	**1.24**	**1.10–1.40**	0.8100
Gallbladder cancer								
Total	163	1339	1262.6	1.10	0.99–1.21	**1.10**	**1.01–1.19**	0.2574
Men	163	511	432.5	**1.26**	**1.08–1.45**	**1.23**	**1.07–1.41**	0.5436
Women	163	828	830.1	1.02	0.90–1.15	1.04	0.94–1.15	0.6723
Lung cancer								
Total	163	19,214	17,394.4	**1.10**	**1.05–1.15**	**1.10**	**1.07–1.12**	**0.0001**
Men	163	17,156	15,336.5	**1.12**	**1.06–1.18**	**1.12**	**1.10–1.15**	**0.0001**
Women	163	2058	2057.8	0.92	0.84–1.00	0.91	0.85–0.97	0.9473
Pleural cancer								
Total	163	394	206.8	**1.71**	**1.34–2.14**	**1.74**	**1.44–2.11**	0.1093
Men	163	284	147.0	**1.84**	**1.39–2.40**	**1.86**	**1.48–2.34**	0.0688
Women	163	110	59.7	**1.52**	**1.04–2.14**	**1.51**	**1.07–2.14**	0.8281
Skin cancer								
Total	163	354	424.0	1.11	0.93–1.31	1.10	0.94–1.27	0.3792
Men	163	209	226.5	1.23	0.99–1.50	**1.26**	**1.03–1.53**	0.4815
Women	163	145	197.5	0.97	0.75–1.23	0.88	0.70–1.10	0.2312
Ovarian cancer								
Women	163	1852	1770.0	**1.14**	**1.05–1.23**	**1.12**	**1.05–1.21**	0.8134
Bladder cancer								
Total	163	4131	3809.9	**1.08**	**1.01–1.16**	**1.07**	**1.02–1.12**	**0.0140**
Men	163	3419	3138.4	**1.10**	**1.02–1.18**	**1.09**	**1.03–1.14**	**0.0092**
Women	163	712	671.5	1.02	0.91–1.15	1.02	0.91–1.13	0.7499
Renal cancer								
Total	163	1918	1651.3	**1.14**	**1.04–1.23**	**1.07**	**1.00–1.15**	0.6497
Men	163	1268	1094.0	**1.12**	**1.02–1.24**	1.07	0.98–1.17	0.4631
Women	163	650	557.4	**1.16**	**1.02–1.31**	1.11	0.99–1.26	0.9937
Brain cancer								
Total	163	2380	2245.9	1.04	0.97–1.12	1.03	0.97–1.10	0.9354
Men	163	1285	1248.8	1.00	0.91–1.09	1.00	0.92–1.08	0.1687
Women	163	1095	997.0	**1.11**	**1.00–1.22**	**1.10**	**1.00–1.20**	0.2573
Non-Hodgkin's lymphoma								
Total	163	2396	2240.2	1.02	0.94–1.11	**1.09**	**1.02–1.16**	0.3802
Men	163	1274	1171.1	1.07	0.97–1.19	**1.12**	**1.03–1.22**	0.7342
Women	163	1122	1069.1	0.96	0.87–1.07	1.03	0.94–1.13	0.1000
Leukemia								
Total	237	5378	4947.1	**1.10**	**1.03–1.17**	**1.06**	**1.01–1.11**	0.6310
Men	237	2956	2713.8	**1.12**	**1.04–1.21**	**1.09**	**1.02–1.16**	0.1279
Women	237	2422	2233.4	1.07	0.98–1.17	1.04	0.97–1.20	0.2602

[a] Number of towns situated at ≤5 km from incinerators and hazardous waste treatment installations as a whole.
[b] Observed deaths.
[c] Expected deaths.
[d] RRs adjusted for population size, percentage illiteracy, farmers and unemployed persons, average persons per household, and mean income.
[e] 95% credible interval.
[f] 95% confidence interval.
[g] Sum of the 33 types of cancer analyzed.

areas surrounding installations for the regeneration of spent baths (RRs = 1.55 and 1.29, respectively); cancers of the gallbladder, lung and pleura in men living near incinerators (RRs = 1.43, 1.19 and 1.98, respectively); skin cancer in men, in the vicinity of solvent treatment installations (RR = 3.30); Hodgkin's lymphoma and kidney cancer in men, in the areas around physico/chemical treatment installations

Table 2
Relative risk of dying from cancers with significant results in towns situated at a distance of 5 km or less from incinerators and hazardous waste treatment installations as a whole, estimated using BYM models and shown with a breakdown by category of industrial activity. Significant results are in bold.

	T[a]	Total			Men			Women		
		Obs[b]	RR[c]	95%CrI[d]	Obs	RR[c]	95%CrI[d]	Obs	RR[c]	95%CrI[d]
All cancers[e]										
Incineration	12	13,051	**1.09**	**1.01–1.18**	8385	1.09	0.99–1.19	4666	1.06	0.98–1.14
Scrap metal + ELVs	52	11,981	**1.04**	**1.00–1.09**	7668	**1.06**	**1.00–1.12**	4313	1.03	0.98–1.08
Oil + oily waste	7	8277	1.08	0.99–1.18	5214	1.09	0.99–1.21	3063	1.07	0.98–1.16
Packaging	2	2471	1.09	0.97–1.22	1591	1.13	0.98–1.29	880	1.02	0.91–1.14
Solvents	6	1108	0.97	0.87–1.08	693	0.98	0.87–1.11	415	0.95	0.84–1.08
Spent baths	15	12412	1.06	0.98–1.14	7833	**1.09**	**1.00–1.18**	4579	1.03	0.95–1.11
Physico/chemical treatment	5	369	1.11	0.97–1.26	230	1.08	0.92–1.27	139	1.15	0.95–1.37
Industrial waste	7	8261	1.07	0.98–1.17	5166	1.09	0.99–1.21	3095	1.01	0.92–1.11
Wastes not otherwise specified	1	144	0.98	0.74–1.26	93	0.99	0.71–1.33	51	0.98	0.70–1.31
Multiple pollutant categories	56	33,634	**1.08**	**1.04–1.13**	21402	**1.10**	**1.05–1.15**	12232	**1.04**	**1.00–1.09**
Stomach cancer										
Incineration	12	801	1.21	0.98–1.47	492	1.11	0.89–1.36	309	**1.38**	**1.09–1.72**
Scrap metal + ELVs	52	794	**1.14**	**1.00–1.29**	508	**1.17**	**1.01–1.34**	286	1.11	0.94–1.31
Oil + oily waste	7	522	1.22	0.97–1.51	326	**1.30**	**1.01–1.64**	196	1.10	0.83–1.42
Packaging	2	193	**1.38**	**1.02–1.82**	134	**1.53**	**1.20–2.04**	59	1.08	0.76–1.49
Solvents	6	76	1.10	0.79–1.47	50	1.15	0.79–1.60	26	1.01	0.63–1.50
Spent baths	15	842	**1.23**	**1.00–1.48**	523	1.20	0.97–1.48	319	1.20	0.96–1.49
Physico/chemical treatment	5	17	0.90	0.50–1.41	15	1.24	0.67–1.99	2	0.35	0.06–0.94
Industrial waste	7	700	**1.33**	**1.05–1.67**	407	1.22	0.94–1.55	293	**1.33**	**1.03–1.68**
Wastes not otherwise specified	1	10	1.25	0.52–2.41	7	1.47	0.53–3.01	3	1.01	0.22–2.51
Multiple pollutant categories	56	2168	**1.17**	**1.05–1.29**	1360	**1.14**	**1.01–1.28**	808	**1.17**	**1.03–1.33**
Colorectal cancer										
Incineration	12	1645	1.07	0.95–1.20	933	1.08	0.94–1.24	712	1.04	0.91–1.18
Scrap metal + ELVs	52	1583	1.05	0.97–1.14	894	1.09	0.98–1.19	689	1.04	0.93–1.14
Oil + oily waste	7	1072	1.09	0.95–1.25	576	1.09	0.92–1.27	496	1.12	0.95–1.31
Packaging	2	347	1.16	0.97–1.37	215	**1.29**	**1.05–1.55**	132	0.99	0.79–1.22
Solvents	6	148	1.05	0.85–1.27	85	1.10	0.85–1.39	63	0.99	0.74–1.28
Spent baths	15	1763	1.11	0.99–1.25	1045	**1.20**	**1.05–1.37**	718	1.04	0.90–1.20
Physico/chemical treatment	5	43	1.03	0.73–1.37	20	0.84	0.51–1.26	23	1.31	0.82–1.91
Industrial waste	7	1201	1.11	0.96–1.28	710	1.15	0.97–1.34	491	1.05	0.88–1.23
Wastes not otherwise specified	1	15	0.90	0.48–1.49	9	0.93	0.41–1.69	6	0.92	0.34–1.81
Multiple pollutant categories	56	4448	**1.09**	**1.02–1.16**	2597	**1.13**	**1.04–1.21**	1851	1.03	0.95–1.12
Liver cancer										
Incineration	12	521	1.26	0.96–1.63	375	1.28	0.97–1.66	146	1.28	0.87–1.81
Scrap metal + ELVs	52	364	1.08	0.90–1.29	273	1.13	0.92–1.36	91	0.97	0.71–1.29
Oil + oily waste	7	290	1.19	0.85–1.60	181	1.14	0.80–1.56	109	1.43	0.88–2.18
Packaging	2	80	1.24	0.83–1.78	59	1.28	0.85–1.85	21	1.14	0.60–1.93
Solvents	6	43	1.17	0.76–1.70	30	1.19	0.74–1.79	13	1.37	0.66–2.42
Spent baths	15	326	**1.43**	**1.09–1.83**	240	1.30	0.98–1.68	86	**1.55**	**1.01–2.25**
Physico/chemical treatment	5	11	1.52	0.72–2.65	8	1.51	0.64–2.81	3	1.75	0.40–4.25
Industrial waste	7	186	1.03	0.73–1.39	133	1.00	0.70–1.37	53	1.14	0.66–1.79
Wastes not otherwise specified	1	3	1.84	0.37–4.84	2	1.61	0.23–4.68	1	3.71	0.22–13.91
Multiple pollutant categories	56	1105	**1.18**	**1.02–1.36**	774	**1.18**	**1.01–1.37**	331	1.20	0.96–1.49
Gallbladder cancer										
Incineration	12	201	1.24	0.98–1.55	81	**1.43**	**1.04–1.92**	120	1.11	0.83–1.44
Scrap metal + ELVs	52	172	1.10	0.90–1.32	65	1.24	0.91–1.62	107	1.04	0.81–1.30
Oil + oily waste	7	116	1.04	0.77–1.36	43	1.23	0.79–1.78	73	1.01	0.71–1.39
Packaging	2	33	1.01	0.66–1.46	12	1.09	0.54–1.87	21	1.01	0.59–1.55
Solvents	6	17	1.22	0.69–1.92	6	1.31	0.49–2.57	11	1.21	0.59–2.07
Spent baths	15	177	1.07	0.83–1.35	64	1.25	0.85–1.76	113	0.97	0.71–1.29
Physico/chemical treatment	5	7	1.75	0.71–3.28	4	2.90	0.85–6.33	3	1.27	0.30–3.02
Industrial waste	7	104	0.94	0.69–1.23	44	1.23	0.78–1.80	60	0.84	0.57–1.17
Wastes not otherwise specified	1	3	2.08	0.47–5.13	1	2.60	0.17–9.31	2	2.24	0.35–6.31
Multiple pollutant categories	56	509	1.13	0.98–1.29	191	**1.25**	**1.01–1.53**	318	1.06	0.89–1.25
Lung cancer										
Incineration	12	2960	**1.17**	**1.01–1.34**	2682	**1.19**	**1.01–1.38**	278	0.94	0.75–1.16
Scrap metal + ELVs	52	2496	1.05	0.96–1.14	2255	1.07	0.98–1.17	241	0.88	0.74–1.05
Oil + oily waste	7	1772	1.13	0.97–1.31	1618	1.15	0.98–1.35	154	0.90	0.67–1.17
Packaging	2	474	1.03	0.85–1.24	414	1.05	0.85–1.28	60	0.96	0.67–1.32
Solvents	6	229	0.94	0.77–1.14	204	0.96	0.77–1.18	25	0.80	0.49–1.19
Spent baths	15	2485	1.12	0.99–1.27	2132	1.13	0.99–1.29	353	1.07	0.84–1.33
Physico/chemical treatment	5	82	1.24	0.94–1.58	69	1.18	0.88–1.54	13	1.72	0.89–2.82
Industrial waste	7	1570	1.09	0.94–1.26	1388	1.13	0.96–1.32	182	0.82	0.62–1.07
Wastes not otherwise specified	1	35	1.20	0.71–1.88	31	1.21	0.69–1.95	4	1.29	0.36–2.95
Multiple pollutant categories	56	7111	**1.14**	**1.06–1.22**	6363	**1.17**	**1.08–1.26**	748	0.91	0.80–1.03
Pleural cancer										
Incineration	12	55	1.55	0.94–2.39	42	**1.98**	**1.09–3.29**	13	1.16	0.52–2.15
Scrap metal + ELVs	52	38	1.37	0.87–2.01	22	1.13	0.63–1.83	16	1.93	0.99–3.27
Oil + oily waste	7	49	**3.45**	**1.97–5.54**	43	**4.85**	**2.50–8.34**	6	1.25	0.41–2.71
Packaging	2	9	1.64	0.66–3.19	7	1.88	0.65–3.98	2	1.44	0.22–4.04
Solvents	6	2	0.93	0.15–2.57	1	0.74	0.05–2.64	1	2.28	0.15–8.12
Spent baths	15	43	1.50	0.86–2.41	35	1.87	0.98–3.18	8	0.93	0.35–1.88

Table 2 (*continued*)

	T[a]	Total			Men			Women		
		Obs[b]	RR[c]	95%CrI[d]	Obs	RR[c]	95%CrI[d]	Obs	RR[c]	95%CrI[d]
Pleural cancer										
Physico/chemical treatment	5	1	1.78	0.12–6.32	0	0	0-inf	1	7.11	0.46–25.47
Industrial waste	7	30	1.78	0.95–2.98	20	1.82	0.83–3.35	10	1.85	0.77–3.56
Wastes not otherwise specified	1	0	0	0-inf	0	0	0-inf	0	0	0-inf
Multiple pollutant categories	56	167	**1.79**	**1.31–2.36**	114	**1.90**	**1.32–2.64**	53	**1.83**	**1.13–2.76**
Connective and soft tissue cancer										
Incineration	12	57	1.04	0.74–1.41	24	0.85	0.53–1.26	33	1.29	0.81–1.92
Scrap metal + ELVs	52	58	1.10	0.81–1.45	30	1.13	0.74–1.60	28	1.12	0.71–1.63
Oil + oily waste	7	52	**1.48**	**1.01–2.06**	22	1.32	0.80–1.99	30	1.47	0.85–2.28
Packaging	2	13	1.18	0.61–1.94	9	1.59	0.72–2.81	4	0.82	0.24–1.81
Solvents	6	2	0.40	0.07–1.08	1	0.46	0.03–1.61	1	0.52	0.04–1.83
Spent baths	15	53	1.11	0.77–1.54	27	1.15	0.72–1.70	26	1.04	0.61–1.62
Physico/chemical treatment	5	0	0	0-inf	0	0	0-inf	0	0	0-inf
Industrial waste	7	41	1.03	0.69–1.46	23	1.23	0.74–1.86	18	0.97	0.53–1.57
Wastes not otherwise specified	1	1	1.94	0.13–6.89	0	0	0-inf	1	4.38	0.28–15.77
Multiple pollutant categories	56	156	1.06	0.85–1.29	84	1.13	0.86–1.44	72	1.00	0.73–1.32
Skin cancer										
Incineration	12	39	1.12	0.71–1.66	22	1.07	0.61–1.69	17	1.15	0.58–1.99
Scrap metal + ELVs	52	35	0.92	0.61–1.30	18	0.86	0.49–1.33	17	0.99	0.55–1.59
Oil + oily waste	7	54	1.50	0.95–2.22	38	**2.14**	**1.31–3.22**	16	1.06	0.50–1.88
Packaging	2	9	1.05	0.45–1.96	8	1.70	0.71–3.18	1	0.36	0.02–1.29
Solvents	6	10	**2.34**	**1.06–4.20**	7	**3.30**	**1.30–6.34**	3	1.49	0.33–3.70
Spent baths	15	47	1.04	0.65–1.55	25	1.12	0.65–1.77	22	0.96	0.48–1.66
Physico/chemical treatment	5	0	0	0-inf	0	0	0-inf	0	0	0-inf
Industrial waste	7	41	1.00	0.60–1.55	28	1.40	0.82–2.19	13	0.68	0.29–1.29
Wastes not otherwise specified	1	1	1.76	0.11–6.44	0	0	0-inf	1	3.75	0.21–14.19
Multiple pollutant categories	56	116	1.14	0.88–1.46	62	1.07	0.77–1.45	54	1.14	0.77–1.60
Vulvar and vaginal cancer										
Incineration	12							42	1.01	0.70–1.40
Scrap metal + ELVs	52							40	1.03	0.72–1.41
Oil + oily waste	7							47	**1.85**	**1.28–2.56**
Packaging	2							6	0.81	0.30–1.59
Solvents	6							6	1.68	0.63–3.27
Spent baths	15							37	0.89	0.58–1.29
Physico/chemical treatment	5							1	1.33	0.09–4.65
Industrial waste	7							41	**1.55**	**1.02–2.24**
Wastes not otherwise specified	1							0	0	0-inf
Multiple pollutant categories	56							96	0.89	0.69–1.12
Ovarian cancer										
Incineration	12							251	1.13	0.95–1.34
Scrap metal + ELVs	52							228	1.08	0.92–1.25
Oil + oily waste	7							151	1.08	0.87–1.33
Packaging	2							59	1.34	0.99–1.75
Solvents	6							23	1.07	0.67–1.56
Spent baths	15							281	**1.29**	**1.07–1.53**
Physico/chemical treatment	5							8	1.32	0.58–2.37
Industrial waste	7							158	1.08	0.86–1.33
Wastes not otherwise specified	1							2	0.94	0.16–2.56
Multiple pollutant categories	56							691	**1.15**	**1.03–1.27**
Bladder cancer										
Incineration	12	567	1.13	0.95–1.34	474	1.13	0.94–1.36	93	0.98	0.75–1.24
Scrap metal + ELVs	52	573	1.11	0.98–1.25	483	**1.16**	**1.02–1.32**	90	0.99	0.77–1.24
Oil + oily waste	7	413	1.09	0.88–1.33	348	1.11	0.88–1.38	65	1.11	0.80–1.48
Packaging	2	128	1.27	0.98–1.62	102	1.24	0.93–1.61	26	1.43	0.90–2.09
Solvents	6	46	0.98	0.69–1.33	36	0.95	0.64–1.33	10	1.26	0.60–2.16
Spent baths	15	528	1.01	0.84–1.20	431	1.02	0.84–1.23	97	0.99	0.74–1.28
Physico/chemical treatment	5	15	1.09	0.60–1.72	13	1.16	0.61–1.89	2	1.03	0.17–2.78
Industrial waste	7	363	1.05	0.84–1.28	302	1.04	0.82–1.30	61	1.00	0.71–1.35
Wastes not otherwise specified	1	5	0.87	0.28–1.84	3	0.66	0.15–1.60	2	2.46	0.40–6.73
Multiple pollutant categories	56	1493	1.09	0.99–1.20	1227	1.09	0.98–1.21	266	1.02	0.86–1.19
Renal cancer										
Incineration	12	240	1.08	0.88–1.30	150	1.04	0.83–1.28	90	1.18	0.88–1.53
Scrap metal + ELVs	52	290	**1.36**	**1.17–1.58**	198	**1.39**	**1.16–1.64**	92	**1.33**	**1.03–1.67**
Oil + oily waste	7	151	1.14	0.90–1.44	99	1.10	0.83–1.42	52	1.17	0.81–1.63
Packaging	2	55	1.24	0.90–1.67	36	1.19	0.80–1.66	19	1.32	0.77–2.03
Solvents	6	21	0.98	0.59–1.46	12	0.84	0.43–1.39	9	1.33	0.61–2.35
Spent baths	15	284	1.06	0.86–1.27	189	1.04	0.83–1.28	95	1.16	0.86–1.52
Physico/chemical treatment	5	14	**2.25**	**1.22–3.61**	10	**2.43**	**1.16–4.17**	4	2.15	0.64–4.66
Industrial waste	7	165	0.95	0.75–1.19	107	0.95	0.73–1.22	58	1.03	0.72–1.39
Wastes not otherwise specified	1	3	1.16	0.27–2.80	3	1.77	0.41–4.26	0	0	0-inf
Multiple pollutant categories	56	695	1.11	0.99–1.25	464	1.11	0.97–1.26	231	1.12	0.93–1.33
Brain cancer										
Incineration	12	322	0.99	0.84–1.16	178	0.97	0.79–1.18	144	1.03	0.82–1.27
Scrap metal + ELVs	52	288	1.00	0.86–1.15	160	0.96	0.80–1.14	128	1.04	0.85–1.26

(continued on next page)

Table 2 (*continued*)

	T[a]	Total			Men			Women		
		Obs[b]	RR[c]	95%CrI[d]	Obs	RR[c]	95%CrI[d]	Obs	RR[c]	95%CrI[d]
Brain cancer										
Oil + oily waste	7	193	1.00	0.80–1.22	90	0.85	0.65–1.09	103	1.24	0.94–1.59
Packaging	2	82	1.31	0.99–1.68	51	**1.41**	**1.01–1.90**	31	1.18	0.77–1.68
Solvents	6	35	1.07	0.73–1.48	22	1.14	0.70–1.69	13	0.98	0.52–1.59
Spent baths	15	300	0.99	0.82–1.19	153	0.94	0.75–1.17	147	1.07	0.84–1.35
Physico/chemical treatment	5	7	0.75	0.31–1.39	6	1.11	0.42–2.15	1	0.37	0.03–1.30
Industrial waste	7	233	1.12	0.90–1.37	132	1.11	0.86–1.41	101	1.15	0.87–1.48
Wastes not otherwise specified	1	9	1.99	0.88–3.60	3	1.32	0.31–3.17	6	**3.29**	**1.20–6.56**
Multiple pollutant categories	56	911	1.06	0.96–1.17	490	1.01	0.89–1.14	421	1.14	0.99–1.30
Thyroid cancer										
Incineration	12	31	0.93	0.59–1.36	7	0.63	0.25–1.20	24	1.09	0.64–1.69
Scrap metal + ELVs	52	52	**1.63**	**1.16–2.20**	22	**1.97**	**1.17–3.00**	30	1.42	0.91–2.06
Oil + oily waste	7	20	1.05	0.59–1.66	6	0.89	0.33–1.77	14	1.13	0.57–1.93
Packaging	2	10	1.51	0.70–2.66	3	1.37	0.32–3.29	7	1.66	0.65–3.18
Solvents	6	5	1.68	0.57–3.45	1	1.20	0.08–4.22	4	2.16	0.63–4.75
Spent baths	15	39	1.14	0.73–1.66	14	1.31	0.67–2.22	25	1.14	0.66–1.79
Physico/chemical treatment	5	2	2.42	0.40–6.57	0	0.00	0-inf	2	3.82	0.62–10.43
Industrial waste	7	25	1.09	0.65–1.68	8	1.08	0.45–2.03	17	1.08	0.57–1.78
Wastes not otherwise specified	1	0	0	0-inf	0	0.00	0-inf	0	0	0-inf
Multiple pollutant categories	56	98	1.06	0.81–1.35	30	0.94	0.59–1.37	68	1.12	0.81–1.49
Hodgkin's lymphoma										
Incineration	12	32	0.87	0.56–1.26	18	0.90	0.51–1.41	14	0.95	0.49–1.56
Scrap metal + ELVs	52	45	1.41	0.99–1.91	27	1.52	0.97–2.21	18	1.38	0.79–2.15
Oil + oily waste	7	15	0.81	0.43–1.32	9	0.89	0.40–1.59	6	0.74	0.27–1.46
Packaging	2	4	0.63	0.19–1.38	3	0.87	0.21–2.06	1	0.53	0.04–1.84
Solvents	6	4	1.14	0.34–2.48	3	1.50	0.36–3.58	1	0.98	0.07–3.43
Spent baths	15	25	0.93	0.56–1.42	11	0.72	0.35–1.25	14	1.12	0.58–1.90
Physico/chemical treatment	5	3	3.39	0.81–8.05	3	**5.64**	**1.34–13.43**	0	0	0-inf
Industrial waste	7	16	0.78	0.42–1.26	10	0.89	0.41–1.58	6	0.71	0.26–1.41
Wastes not otherwise specified	1	1	3.46	0.23–12.26	1	5.95	0.40–21.08	0	0	0-inf
Multiple pollutant categories	56	93	1.04	0.79–1.32	48	0.96	0.67–1.30	45	1.21	0.83–1.68
Leukemia										
Incineration	16	416	1.05	0.97–1.13	245	1.08	0.98–1.18	171	1.03	0.93–1.13
Scrap metal + ELVs	56	430	**1.14**	**1.01–1.28**	227	1.09	0.93–1.26	203	**1.23**	**1.04–1.43**
Oil + oily waste	24	387	1.08	0.90–1.28	216	1.14	0.91–1.39	171	1.03	0.80–1.28
Packaging	9	135	1.15	0.89–1.44	79	1.11	0.80–1.48	56	1.21	0.85–1.64
Solvents	4	33	1.29	0.94–1.70	16	1.28	0.83–1.82	17	1.35	0.85–1.98
Spent baths	14	195	1.01	0.85–1.18	112	1.12	0.92–1.35	83	0.86	0.68–1.06
Physico/chemical treatment	8	1573	1.33	0.74–2.08	840	0.97	0.37–1.87	733	1.95	0.90–3.39
Industrial waste	13	354	1.01	0.84–1.21	188	1.04	0.83–1.28	166	0.99	0.77–1.24
Wastes not otherwise specified	11	22	1.03	0.30–2.25	12	1.40	0.33–3.34	10	0.79	0.06–2.77
Multiple pollutant categories	82	1833	**1.13**	**1.04–1.23**	1021	**1.14**	**1.02–1.26**	812	1.12	0.99–1.26

[a] Number of towns situated at ≤5 km from incinerators and hazardous waste treatment installations as a whole.
[b] Observed deaths.
[c] RRs adjusted for population size, percentage illiteracy, farmers and unemployed persons, average persons per household, and mean income.
[d] 95% credible interval.
[e] Sum of the 33 types of cancer analyzed.

(RRs = 5.64 and 2.43, respectively); bladder and thyroid cancer in men and leukemias in women in the vicinity of scrap metal + ELV recycling installations (RRs = 1.16, 1.97 and 1.23, respectively); brain cancer in women living near other waste treatment installations (RR = 3.29); and cancers of the pleura in men, vulva and vagina in women, and connective tissue in the total population (RRs = 4.85, 1.85 and 1.48, respectively), in the environs of oil and oily waste treatment installations. If we analyze the results on stratifying risk by category of industrial activity, the following associations were found between malignant tumors and residential proximity to certain types of installations: a) "Incinerators", and tumors of the lung, pleura and gallbladder (men) and stomach (women); b) "Installations for the recycling of scrap metal and ELVs", and cancer of the kidney (men and women), tumors of the stomach, bladder and thyroid (men) and leukemia (women); c) "Installations for the treatment of used oil and oily waste", and cancer of the connective tissue (total population), tumors of the stomach, pleura and skin (men), and of vulva and vagina (women); d) "Packaging recycling installations", and tumors of the stomach, colon–rectum and brain (men); e) "Installations for the recovery of used solvents", and skin cancer (men); f) "Installations for the regeneration of spent baths", and cancer of the stomach (total population), colorectal cancer (men), and tumors of the liver and ovary (women); g) "Installations for physico/chemical treatment of wastes", and cancer of the kidney (men); h) "Industrial waste treatment installations", and tumors of the stomach, vulva and vagina (women); and, i) "Installations for the treatment of wastes not otherwise specified", and cancer of the brain (women). In addition, towns situated near several installations of "Multiple pollutant categories" displayed significant results for malignant tumors of the stomach and pleura (men and women), colon–rectum, liver, gallbladder, lung and leukemia (men), and ovary (women).

Table 3 shows the RRs in the vicinity of specific incinerators and hazardous waste treatment facilities which registered statistically significant excess risks in the "near vs. far" analysis and a number of observed deaths ≥15. There are a total of 3 incinerators, 15 installations for the recycling of scrap metal and ELVs, 6 installations for the treatment of used oil and oily waste, 3 packaging recycling installations, 2 installations for the recovery of used solvents, 3 installations for the regeneration of spent baths, 3 installations for physico/chemical treatments of wastes, 4 industrial waste treatment installations, and 6 installations for the treatment of wastes not otherwise specified, with significant results. Many of the installations displayed considerably high RRs for more than one tumor simultaneously, and this was especially true for installations '372', '4699' and '5692' ("Scrap metal + ELVs"), '3710' ("Industrial waste"), and '6053' ("Wastes not otherwise specified”), with statistically significant results for 6 tumors, and installations ‘3055’ and ‘7476’ (“Scrap metal + ELVs”), ‘3713’ (“Spent baths”), ‘3110’ (“Physico/chemical treatment”), ‘3711’ (“Industrial waste”), and ‘7478 (“Wastes not otherwise specified”), with statistically significant results for 5 tumors. It is also noteworthy to note that there are 11 facilities with significant excess risk for all cancers combined: installations ‘372’ (RR = 1.28 in women), ‘3055’ (RR = 1.10 in the total population), ‘5692’ (RR = 1.30 in women), ‘6051’ (RR = 1.21 in women), ‘3050’ (RR = 1.19 in women), ‘3110’ (RR = 1.30 in women), and ‘7478’ (RR = 1.10 in the total population), located in the province of Barcelona; installations ‘4699’ (RR = 1.13 in men), ‘5910’ (RR = 1.27 in men), ‘3710’ (RR = 1.13 in men), and ‘3711’ (RR = 1.33 in men), located in the province of Vizcaya); and, installation ‘5493’ (RR = 1.20 in men), located in the province of Granada.

4. Discussion

This study is one of the first to use IPPC- and E-PRTR-registered industrial data to explore the effects of industrial waste-treatment on cancer mortality in neighboring towns. In general, our results suggest that there is a moderate increased risk of dying of all cancers combined, higher among men than among women, in the vicinity of Spanish incinerators and hazardous waste treatment plants as a whole. Stratifying the risk by industrial activity, high statistically significant excess risks were detected in towns lying near “Incinerators” (total population), “Installations for the recycling of scrap metal and ELVs”, “Installations for the regeneration of spent baths” (men), and various installations of “Multiple pollutant categories” (men and women).

On analyzing cancers individually, significant excess risks were observed for malignant tumors of the stomach, liver, pleura and kidney (men and women), colon–rectum, lung, bladder, gallbladder and leukemia (men), and brain and ovary (women). Furthermore, on stratifying risk by category of industrial activity, the following associations were found between other malignant tumors and residential proximity to certain types of installations: “Installations for the recycling of scrap metal and ELVs”, and tumors of the stomach and thyroid (men); “Installations for the treatment of used oil and oily waste”, and cancer of the connective tissue (total population), tumors of the skin (men), and of the vulva and vagina (women); “Installations for the recovery of used solvents”, and skin tumor (men); and, “Industrial waste treatment installations”, and tumor of the vulva and vagina (women).

The fact that statistically significant results, with RRs ≥1.10, appeared mainly for tumors of both the digestive and respiratory system (in total population), leads us to suspect two possible routes of exposure to the pollution released by these installations, namely: direct exposure to pollutants released to air; and indirect exposure, both to pollutants and liquid effluents which are released to water and can then pass into the soil and aquifers, and pollutants which are released to air and then settle on plants. In such cases, the toxins may pass into the trophic chain, affecting the population.

The hypothesis that some excess cancer mortality may be due to population exposure to industrial pollution is reinforced by recent studies that have reported associations between residential proximity to certain types of industrial installations and certain malignant tumors (Garcia-Perez et al., 2010, 2012; Lopez-Abente et al., 2012; Musti et al., 2009; Tsai et al., 2009). As regards incinerators and hazardous waste treatment plants, studies have almost exclusively focused on the environs of incinerators, where associations have been found with some tumors, such as NHL (Floret et al., 2003; Viel et al., 2011), soft tissue sarcomas (Comba et al., 2003), and childhood tumors (Knox, 2000).

Ecologic studies, such as that reported here, are proposing new hypotheses and lines of research with respect to population exposure to industrial pollution. In this regard, one of the principal strengths of our study resides in the completeness of its exploratory analysis, which consisted of an in-depth examination of mortality due to 33 types of cancer with reference to different categories of industrial activity. Another strength was its use of different methodological approaches to perform the statistical analysis: one, based on a hierarchical spatial model at a municipal level, with inclusion of explanatory variables (BYM model), in which the use of spatial terms in the model, not only meant that it was less susceptible to the presence of the ecological fallacy (Clayton et al., 1993), but also ensured that the geographic heterogeneity of the distribution of mortality was taken into account; and the other, based on a Poisson mixed regression model, was justified by its ease of adjustment and shorter computation times. Although the results in the two models used are not very different in general, the presence of spatial autocorrelation in some of the tumors studied renders the use of spatial models advisable. Moreover, the method of estimation afforded by INLA, as an alternative to Markov chain Monte Carlo methods, amounts to a qualitative leap in the use of hierarchical models with explanatory variables (Rue et al., 2009). A consideration to bear in mind is that mixed models seem to be more sensitive to detect potential statistical associations than spatial models, which are more restrictive. An example of the above mentioned can be seen in our results on NHL in males, where the mixed model provided statistically significant results (RR = 1.12, 95%CI = 1.03–1.22) whereas the model BYM did not show a statistically significant association (RR = 1.07, 95%CrI = 0.97–1.19).

Further advantages of the study are: its high statistical power, thanks to the inclusion of a great number of reported deaths, a factor that enables it to identify excess mortality of a lower magnitude, in line with the expected effects of environmental exposures; analysis of risk in the vicinity of industrial activities such as ELV-disposal or scrap-metal recycling plants, which had never before been studied as a whole, as well as detailed individual analyses of the respective installations; elimination for study purposes of those installations that had come into operation most recently, and whose possible influence on tumor development is debatable if the minimum latency periods of the tumors analyzed are taken into account; and inclusion of towns lying close to industries other than incinerators and hazardous waste treatment installations, as the “intermediate category” in the analyses, something that avoids the confounding effect of such industries (which release toxic substances that could be related to the tumors under study) and allows for the establishment of a “clean” reference group made up of towns having no industry in their vicinity.

Aside from the limitations inherent to all ecologic studies, in our case mention should also be made of the following: the inclusion of many variables in the models that could make the analyses very susceptible to type I error; the non-inclusion of possible confounding factors that might be associated with distance (though adjustment for socioeconomic variables goes some way to mitigating this lack of information, since many life-style-related risk factors, such as smoking, alcohol consumption, type of diet or infectious agents, show a distribution correlated with socioeconomic status (Prattala et al., 2009; Woitas-Slubowska et al., 2010)); the use of distance from town of residence to industrial centers as a “proxy” of population exposure to industrial pollution, based on the assumption of an isotropic model, since real exposure may depend on prevailing wind patterns or geographical landforms (though this would limit the capacity for detecting positive results, without invalidating the associations found); and the use of mortality rather than incidence data, due to the absence of a national population-based incidence register (though in Spain, tumors with lower survival rates are well represented by death certificates (Perez-Gomez et al., 2006)).

A critical decision when designing the study was the choice of categories of industrial activity for stratifying risk in the analyses. In this respect, we chose to construct the categories according to the characteristics of the waste applicable and type of treatment used (Agència de Residus de Catalunya, 2012; Special Territorial Plan of Waste Management (PTEOR), 2012). Furthermore, landfills, composting

Table 3
Relative risk of dying from cancers with significant results and a number of observed deaths ≥15 in towns situated at a distance of less than 5 km from specific incinerators and hazardous waste treatment installations, estimated using BYM models. Significant results are in bold.

Industrial activity[a]	PRTR Code		T[b]	Obs[c]	BYM model	
					RR[d]	95% CrI[e]
All cancers[f]						
2	372	Total	4	949	**1.11**	**1.01–1.23**
		Men	4	591	1.03	0.91–1.17
		Women	4	358	**1.28**	**1.10–1.48**
2	3055	Total	5	1370	**1.10**	**1.00–1.20**
		Men	5	916	1.10	0.98–1.22
		Women	5	454	1.09	0.95–1.25
2	4699	Total	6	4803	1.10	0.99–1.21
		Men	6	3184	**1.13**	**1.00–1.27**
		Women	6	1619	1.04	0.91–1.19
2	5692	Total	3	864	1.09	0.98–1.21
		Men	3	531	0.99	0.87–1.13
		Women	3	333	**1.30**	**1.11–1.51**
2	6051	Total	3	2441	**1.11**	**1.00–1.23**
		Men	3	1612	1.06	0.94–1.20
		Women	3	829	**1.21**	**1.04–1.39**
3	5493	Total	3	561	**1.18**	**1.00–1.38**
		Men	3	350	**1.20**	**1.00–1.42**
		Women	3	211	1.11	0.90–1.36
3	5910	Total	3	472	**1.25**	**1.08–1.43**
		Men	3	309	**1.27**	**1.07–1.51**
		Women	3	163	1.21	0.97–1.47
4	3050	Total	3	1308	**1.12**	**1.01–1.24**
		Men	3	847	1.08	0.95–1.23
		Women	3	461	**1.19**	**1.02–1.38**
7	3110	Total	3	654	1.09	0.97–1.22
		Men	3	398	0.99	0.86–1.14
		Women	3	256	**1.30**	**1.09–1.52**
8	3710	Total	6	4803	1.10	0.99–1.21
		Men	6	3184	**1.13**	**1.00–1.27**
		Women	6	1619	1.04	0.91–1.19
8	3711	Total	4	713	**1.26**	**1.11–1.42**
		Men	4	478	**1.33**	**1.14–1.54**
		Women	4	235	1.13	0.93–1.35
9	7478	Total	5	1370	**1.10**	**1.00–1.20**
		Men	5	916	1.10	0.98–1.22
		Women	5	454	1.09	0.95–1.25
Esophageal cancer						
2	3055	Total	5	45	**1.59**	**1.00–2.38**
		Men	5	44	**1.74**	**1.08–2.64**
		Women	5	1	0.47	0.05–1.51
9	7478	Total	5	45	**1.59**	**1.00–2.38**
		Men	5	44	**1.74**	**1.08–2.64**
		Women	5	1	0.47	0.05–1.51
Stomach cancer						
2	6049	Total	5	49	1.63	0.96–2.58
		Men	5	27	1.35	0.73–2.29
		Women	5	22	**2.26**	**1.00–4.29**
3	5493	Total	3	36	1.31	0.82–1.94
		Men	3	25	**1.73**	**1.02–2.68**
		Women	3	11	0.82	0.36–1.51
6	4719	Total	8	43	**1.72**	**1.03–2.69**
		Men	8	31	1.60	0.87–2.70
		Women	8	12	1.98	0.77–4.07
6	4833	Total	2	94	**1.59**	**1.05–2.32**
		Men	2	44	1.27	0.73–2.05
		Women	2	50	**2.26**	**1.24–3.78**
Colorectal cancer						
2	372	Total	4	134	1.25	0.98–1.58
		Men	4	71	1.14	0.82–1.52
		Women	4	63	**1.41**	**1.00–1.92**
2	4699	Total	6	605	1.19	0.95–1.47
		Men	6	380	**1.35**	**1.02–1.74**
		Women	6	225	1.00	0.72–1.37
2	7476	Total	2	433	**1.35**	**1.04–1.72**
		Men	2	247	**1.48**	**1.09–1.96**
		Women	2	186	1.23	0.81–1.75
6	3713	Total	6	1976	1.19	0.96–1.46
		Men	6	1182	**1.34**	**1.03–1.72**
		Women	6	794	1.03	0.74–1.38

Industrial activity[a]	PRTR code		T[b]	Obs[c]	BYM model	
					RR[d]	95% CrI[e]
Pancreatic cancer						
2	5680	Total	5	24	**1.94**	**1.11–3.09**
		Men	5	12	1.35	0.61–2.47
		Women	5	12	**3.15**	**1.38–5.95**
2	5691	Total	3	27	**2.08**	**1.27–3.14**
		Men	3	15	**2.06**	**1.07–3.47**
		Women	3	12	**2.16**	**1.02–3.84**
2	7476	Total	2	137	1.36	0.90–1.95
		Men	2	71	1.09	0.62–1.77
		Women	2	66	**1.86**	**1.04–3.06**
7	3110	Total	3	32	1.27	0.77–1.94
		Men	3	23	**1.86**	**1.05–3.00**
		Women	3	9	0.76	0.31–1.45
8	65	Total	2	388	**1.67**	**1.01–2.60**
		Men	2	202	**2.08**	**1.08–3.66**
		Women	2	186	1.30	0.61–2.41
8	6749	Total	9	299	1.30	0.85–1.90
		Men	9	153	**1.79**	**1.03–2.89**
		Women	9	146	0.93	0.49–1.58
9	6053	Total	2	137	1.36	0.90–1.95
		Men	2	71	1.10	0.62–1.78
		Women	2	66	**1.84**	**1.03–3.05**
Peritoneal cancer						
6	3713	Total	6	42	2.00	0.59–5.00
		Men	6	19	**9.04**	**4.80–32.66**
		Women	6	23	0.93	0.22–2.80
Laryngeal cancer						
2	372	Total	4	21	**1.91**	**1.02–3.21**
		Men	4	21	**2.11**	**1.12–3.58**
		Women	4	0	0	0-inf
2	3055	Total	5	31	**1.88**	**1.09–3.01**
		Men	5	30	**1.99**	**1.13–3.23**
		Women	5	1	1.49	0.13–5.00
2	5692	Total	3	20	**1.96**	**1.03–3.32**
		Men	3	20	**2.17**	**1.13–3.70**
		Women	3	0	0	0-inf
9	7478	Total	5	31	**1.88**	**1.09–3.01**
		Men	5	30	**1.99**	**1.13–3.23**
		Women	5	1	1.49	0.13–5.00
Lung cancer						
2	4699	Total	6	990	1.20	0.96–1.48
		Men	6	893	**1.30**	**1.02–1.64**
		Women	6	97	0.77	0.47–1.19
2	7476	Total	2	566	**1.39**	**1.05–1.81**
		Men	2	511	**1.43**	**1.07–1.90**
		Women	2	55	1.04	0.55–1.84
3	5493	Total	3	135	**1.39**	**1.04–1.81**
		Men	3	120	1.33	0.98–1.76
		Women	3	15	**2.27**	**1.06–4.14**
3	7412	Total	1	819	1.31	0.97–1.71
		Men	1	743	**1.40**	**1.02–1.87**
		Women	1	76	0.81	0.43–1.38
5	1678	Total	2	164	1.24	0.98–1.56
		Men	2	143	**1.29**	**1.00–1.63**
		Women	2	21	0.89	0.50–1.46
8	3710	Total	6	990	1.20	0.96–1.48
		Men	6	893	**1.30**	**1.02–1.64**
		Women	6	97	0.77	0.47–1.19
8	3711	Total	4	141	**1.38**	**1.02–1.82**
		Men	4	126	**1.45**	**1.06–1.95**
		Women	4	15	1.09	0.51–2.00
9	6053	Total	2	566	**1.37**	**1.05–1.79**
		Men	2	511	**1.42**	**1.07–1.88**
		Women	2	55	1.04	0.55–1.84
Pleural cancer						
2	4699	Total	6	30	4.75	0.74–13.97
		Men	6	25	**4.33**	**4.56–13.64**
		Women	6	5	inf	0-inf
6	3713	Total	6	61	2.82	0.73–9.02

Table 3 (*continued*)

Industrial activity[a]	PRTR Code		T[b]	Obs[c]	BYM model	
					RR[d]	95% CrI[e]
Colorectal cancer						
7	3110	Total	3	87	1.14	0.86–1.49
		Men	3	41	0.92	0.62–1.31
		Women	3	46	**1.49**	**1.01–2.09**
8	3710	Total	6	605	1.19	0.95–1.47
		Men	6	380	**1.35**	**1.02–1.74**
		Women	6	225	1.00	0.72–1.37
9	6053	Total	2	433	**1.35**	**1.04–1.71**
		Men	2	247	**1.47**	**1.08–1.95**
		Women	2	186	1.23	0.81–1.75
Liver cancer						
2	7476	Total	2	99	**2.40**	**1.40–3.87**
		Men	2	73	**2.59**	**1.42–4.36**
		Women	2	26	2.29	0.75–5.34
3	1612	Total	1	176	**2.25**	**1.23–3.77**
		Men	1	102	1.91	0.92–3.56
		Women	1	74	**3.79**	**1.32–8.43**
6	4833	Total	2	58	2.51	0.98–5.29
		Men	2	34	2.12	0.69–4.96
		Women	2	24	**3.65**	**1.08–9.53**
9	6053	Total	2	99	**2.36**	**1.37–3.79**
		Men	2	73	**2.56**	**1.40–4.30**
		Women	2	26	2.17	0.71–5.08
Connective and soft tissue						
3	6789	Total	2	34	2.55	0.62–7.25
		Men	2	19	**9.41**	**3.10–35.45**
		Women	2	15	0.90	0.02–3.65
8	6749	Total	9	36	2.28	0.52–6.03
		Men	9	19	**6.65**	**4.82–23.45**
		Women	9	17	0.93	0.11–3.55
Melanoma						
2	5063	Total	1	16	**19.55**	**10.16–79.17**
		Men	1	10	NE[g]	NE[g]
		Women	1	6	NE[g]	NE[g]
6	3713	Total	6	114	1.80	0.82–3.46
		Men	6	56	1.54	0.55–3.49
		Women	6	58	**2.58**	**1.18–6.89**
Skin cancer						
3	7412	Total	1	39	**6.39**	**1.35–17.89**
		Men	1	29	**17.38**	**2.92–52.97**
		Women	1	10	3.04	0.35–10.62
Vulvar and vaginal cancer						
3	7412	Women	1	21	**6.66**	**1.06–23.49**
Uterine cancer						
4	5557	Women	1	27	**2.12**	**1.00–3.94**
8	3711	Women	4	15	**2.27**	**1.05–4.17**
Ovarian cancer						
1	2438	Women	2	51	**1.95**	**1.09–3.29**
2	5685	Women	4	17	**2.72**	**1.38–4.70**
2	7328	Women	3	15	**2.68**	**1.39–4.48**
3	445	Women	8	156	**1.49**	**1.03–2.09**
4	3050	Women	3	28	**1.82**	**1.04–2.94**
4	5557	Women	1	36	**2.45**	**1.24–4.31**
5	2999	Women	3	16	**2.58**	**1.29–4.52**
7	3110	Women	3	17	**1.98**	**1.02–3.39**
7	3452	Women	4	57	**2.39**	**1.39–3.84**
9	6431	Women	7	151	**1.46**	**1.00–2.06**
Prostate cancer						
3	5493	Men	3	43	**1.66**	**1.10–2.38**
Bladder cancer						
2	5680	Total	5	24	**2.39**	**1.34–3.86**
		Men	5	21	**2.68**	**1.45–4.45**
		Women	5	3	1.36	0.24–3.76
2	7476	Total	2	116	1.48	0.93–2.19
Pleural cancer						
		Men	6	50	**2.44**	**3.64–7.75**
		Women	6	11	inf	0-inf
8	65	Total	2	27	**8.73**	**1.32–35.97**
		Men	2	19	**12.23**	**1.41–41.46**
		Women	2	8	NE[g]	NE[g]
8	3710	Total	6	30	4.75	0.74–13.97
		Men	6	25	**4.33**	**4.57–13.64**
		Women	6	5	inf	0-inf
8	6749	Total	9	25	3.44	0.86–9.74
		Men	9	10	1.24	0.26–4.47
		Women	9	15	**18.61**	**3.58–79.24**
Bone cancer						
1	467	Total	3	29	**2.89**	**1.04–6.64**
		Men	3	23	**12.40**	**11.67–47.49**
		Women	3	6	0.88	0.14–2.63
1	4857	Total	3	29	**2.89**	**1.05–6.64**
		Men	3	23	**12.29**	**17.17–46.76**
		Women	3	6	0.88	0.14–2.63
6	3713	Total	6	28	2.31	0.02–7.79
		Men	6	20	**3.18**	**2.61–11.22**
		Women	6	8	**14.49**	**1.79–73.89**
8	65	Total	2	26	**6.90**	**1.65–22.49**
		Men	2	15	3.26	0.40–13.19
		Women	2	11	NE[g]	NE[g]
Ill-defined tumors						
2	5664	Total	2	36	**1.74**	**1.15–2.49**
		Men	2	28	**2.47**	**1.51–3.74**
		Women	2	8	0.88	0.36–1.67
2	5682	Total	6	168	**1.36**	**1.00–1.81**
		Men	6	94	1.28	0.86–1.83
		Women	6	74	1.53	0.97–2.28
6	4833	Total	2	115	1.41	0.82–2.22
		Men	2	**70**	**2.16**	**1.17–3.64**
		Women	2	45	0.88	0.43–1.62
Non-Hodgkin's lymphoma						
1	467	Total	3	215	**1.49**	**1.02–2.12**
		Men	3	113	1.63	0.95–2.64
		Women	3	102	1.45	0.85–2.35
1	4857	Total	3	215	**1.49**	**1.02–2.12**
		Men	3	113	1.64	0.96–2.67
		Women	3	102	1.44	0.84–2.33
2	5692	Total	3	30	**1.67**	**1.00–2.59**
		Men	3	18	1.86	0.93–3.26
		Women	3	12	1.52	0.68–2.85
2	6051	Total	3	82	**1.60**	**1.03–2.39**
		Men	3	49	**2.15**	**1.15–3.75**
		Women	3	33	1.23	0.65–2.14
3	5910	Total	3	15	**2.22**	**1.04–4.04**
		Men	3	9	**3.96**	**1.45–8.36**
		Women	3	6	1.26	0.36–2.94
8	3711	Total	4	21	**2.01**	**1.02–3.50**
		Men	4	12	**3.40**	**1.36–6.91**
		Women	4	9	1.22	0.42–2.66
Myeloma						
2	372	Total	4	21	**2.08**	**1.11–3.49**
		Men	4	10	1.70	0.68–3.42
		Women	4	11	**2.72**	**1.09–5.53**
2	3055	Total	5	31	**1.91**	**1.11–3.04**
		Men	5	20	**2.25**	**1.09–4.09**
		Women	5	11	1.56	0.64–3.09
2	5692	Total	3	21	**2.28**	**1.21–3.84**
		Men	3	10	1.87	0.74–3.75
		Women	3	11	**2.98**	**1.19–6.08**
6	3713	Total	6	227	**1.69**	**1.02–2.65**
		Men	6	115	**2.62**	**1.25–4.92**
		Women	6	112	1.21	0.60–2.20
7	3110	Total	3	16	**2.37**	**1.18–4.18**
		Men	3	7	1.87	0.64–4.05
		Women	3	9	**3.19**	**1.18–6.76**
7	3452	Total	4	54	**1.93**	**1.10–3.22**

(*continued on next page*)

Table 3 (*continued*)

Industrial activity[a]	PRTR Code		T[b]	Obs[c]	BYM model	
					RR[d]	95% CrI[e]
Bladder cancer						
		Men	2	97	**1.68**	**1.03–2.56**
		Women	2	19	0.85	0.33–1.81
9	6053	Total	2	116	1.47	0.92–2.19
		Men	2	97	**1.67**	**1.01–2.55**
		Women	2	19	0.86	0.33–1.81
Brain cancer						
1	2438	Total	2	69	1.14	0.70–1.79
		Men	2	27	0.78	0.37–1.66
		Women	2	42	**2.05**	**1.01–3.72**
2	372	Total	4	30	1.49	0.89–2.31
		Men	4	13	0.99	0.47–1.78
		Women	4	17	**2.59**	**1.17–4.92**
2	4699	Total	6	111	1.42	0.92–2.10
		Men	6	59	**1.90**	**1.04–3.20**
		Women	6	52	1.12	0.59–1.90
2	5692	Total	3	27	1.43	0.84–2.25
		Men	3	12	0.98	0.45–1.78
		Women	3	15	**2.50**	**1.09–4.86**
3	5910	Total	3	16	**2.25**	**1.11–3.95**
		Men	3	8	2.63	0.94–5.52
		Women	3	8	2.05	0.73–4.36
4	3050	Total	3	46	**1.60**	**1.02–2.40**
		Men	3	25	1.36	0.76–2.24
		Women	3	21	**2.14**	**1.03–3.92**
7	2088	Total	3	37	**1.91**	**1.02–3.24**
		Men	3	22	1.97	0.84–3.86
		Women	3	15	1.88	0.68–4.12
8	3710	Total	6	111	1.42	0.92–2.10
		Men	6	59	**1.90**	**1.04–3.20**
		Women	6	52	1.12	0.59–1.90
8	3711	Total	4	25	**2.42**	**1.31–4.03**
		Men	4	14	**3.42**	**1.47–6.66**
		Women	4	11	1.78	0.70–3.60
9	2089	Total	3	43	**1.92**	**1.03–3.28**
		Men	3	22	1.52	0.62–3.07
		Women	3	21	2.47	0.94–5.31
9	7403	Total	3	43	**1.92**	**1.03–3.28**
		Men	3	22	1.52	0.62–3.07
		Women	3	21	2.47	0.94–5.31
Thyroid cancer						
1	467	Total	3	21	1.11	0.38–2.59
		Men	3	6	0.66	0.13–2.18
		Women	3	15	**2.05**	**1.52–6.14**
1	4857	Total	3	21	1.10	0.38–2.57
		Men	3	6	0.65	0.14–2.14
		Women	3	15	**2.04**	**1.49–6.13**

Industrial activity[a]	PRTR code		T[b]	Obs[c]	BYM model	
					RR[d]	95% CrI[e]
Myeloma						
		Men	4	23	1.73	0.78–3.34
		Women	4	31	**2.24**	**1.05–4.32**
9	7478	Total	5	31	**1.91**	**1.11–3.04**
		Men	5	20	**2.25**	**1.09–4.09**
		Women	5	11	1.56	0.64–3.09
Leukemia						
2	372	Total	4	42	**1.59**	**1.03–2.30**
		Men	4	22	1.27	0.72–2.05
		Women	4	20	**2.28**	**1.16–3.98**
2	3055	Total	5	59	**1.58**	**1.08–2.23**
		Men	5	36	1.56	0.96–2.38
		Women	5	23	1.69	0.90–2.87
2	3594	Total	10	50	**1.63**	**1.06–2.40**
		Men	10	28	1.70	0.96–2.79
		Women	10	22	1.65	0.84–2.88
2	4699	Total	6	136	1.24	0.82–1.80
		Men	6	77	0.96	0.58–1.51
		Women	6	59	**1.97**	**1.01–3.49**
2	5680	Total	5	16	**2.31**	**1.18–3.95**
		Men	5	10	**2.83**	**1.16–5.51**
		Women	5	6	1.92	0.63–4.13
2	5692	Total	3	39	**1.60**	**1.03–2.35**
		Men	3	20	1.26	0.69–2.05
		Women	3	19	**2.37**	**1.19–4.18**
2	6051	Total	3	81	1.28	0.85–1.86
		Men	3	43	1.01	0.60–1.60
		Women	3	38	**2.02**	**1.02–3.67**
3	6789	Total	2	147	**2.11**	**1.13–3.65**
		Men	2	85	**2.87**	**1.25–5.82**
		Women	2	62	1.57	0.63–3.27
4	3120	Total	5	49	**1.60**	**1.07–2.29**
		Men	5	25	1.25	0.72–1.97
		Women	5	24	**2.37**	**1.26–4.05**
8	3710	Total	6	136	1.24	0.82–1.80
		Men	6	77	0.96	0.58–1.51
		Women	6	59	**1.97**	**1.01–3.49**
9	5703	Total	5	49	**1.60**	**1.07–2.29**
		Men	5	25	1.25	0.72–1.97
		Women	5	24	**2.37**	**1.26–4.05**
9	6053	Total	2	109	**1.65**	**1.00–2.51**
		Men	2	57	1.69	0.89–2.88
		Women	2	52	1.78	0.97–3.00
9	7478	Total	5	59	**1.58**	**1.08–2.23**
		Men	5	36	1.56	0.96–2.38
		Women	5	23	1.69	0.90–2.87

[a] 1 = incineration. 2 = scrap metal + ELVs. 3 = oil + oily waste. 4 = packaging. 5 = solvents. 6 = spent baths. 7 = physico/chemical treatment. 8 = industrial waste. 9 = wastes not otherwise specified.
[b] Number of towns situated at ≤5 km from specific incinerators and hazardous waste treatment installations.
[c] Observed deaths.
[d] RRs adjusted for population size, percentage illiteracy, farmers and unemployed persons, average persons per household, and mean income.
[e] 95% credible interval.
[f] Sum of the 33 types of cancer analyzed.
[g] Not estimated: risk could not be estimated using INLA.

plants, and waste water treatment facilities were not included in our study, since they do not come under IPPC categories 5.1 and 5.2.

Another aspect to consider is that poor communities are forced to live in polluted areas, near waste and industrial sites (Parodi et al., 2005), so it is particularly important to emphasize that the results and conclusions are not simply a reflection of socioeconomic status.

4.1. Incinerators

Incineration is a thermal treatment that generates recognized and suspected carcinogens such as dioxins, arsenic, chromium, benzene, PAHs, cadmium, lead, tetrachloroethylene, hexachlorobenzene, nickel, and naphthalene (European Commission, 2006).

Epidemiologic studies addressing increases in cancer in towns lying in the vicinity of incinerators have provided limited evidence (Porta et al., 2009): the results of a study on incidence of cancer in the environs of 72 incinerators in the United Kingdom (Elliott et al., 1996) which showed statistically significant increases in certain cancers, were critically reviewed (Elliott et al., 2000) and, according to the authors, these results could be affected by different biases, which would in turn mean that the observed effects would not be attributable to incinerator emissions. Nevertheless, studies undertaken in other countries have reported excess risks for hematologic tumors, lung cancer, and some cancers of the digestive system (Biggeri et al., 1996; Comba et al., 2003; Floret et al., 2003; Knox, 2000; Ranzi et al., 2011; Viel et al., 2011).

The results reported in our study show excess risks for all cancers combined and for lung cancer, and in particular, marked increases in risk of tumors of the pleura and gallbladder (men) and stomach (women). Individualized analyses of the installations revealed statistically significant RRs in NHL in the vicinity of installations '467' and '4857' situated in the same town, as well as high excess risks of tumors of the ovary and brain in women in the environs of incinerator '2438'.

4.2. Installations for the recycling of scrap metal and scrapping of motor vehicles

One of the most surprising results of our study is the excess risk detected – statistically significant in all cancers combined, malignant tumors of the stomach, bladder, and thyroid (in men), renal cancer (in men and women), and leukemia (in women), and very close to statistical significance in malignant tumors of the colon–rectum and lung (in men), pleural cancer (in women), and Hodgkin's lymphoma (in the total population) – in the vicinity of installations engaged in the recycling of scrap metal and the scrapping/decontamination of ELVs. The reason for pooling these activities into one category for analysis purposes was because, until relatively recently, these types of waste came within the scope of the Spanish scrap metal sector (Muñoz et al., 2011). In Europe, ELVs have been defined as hazardous waste since 2002, due to the toxic composition of their constituent materials, i.e., used oils, brake liquid, oil filters, absorbent materials, batteries, and fuel. The treatment applied by these types of installations (Joung et al., 2007; Nourreddine, 2007; Santini et al., 2012) generates recognized and suspected carcinogens, such as dioxins, furans, dioxin-like PCBs, lead, chromium, PAHs, cadmium or nickel, and other hazardous substances, such as shredder dusts.

To the best of our knowledge, no epidemiologic studies have been conducted on populations living near these types of installations. Insofar as occupational exposure is concerned, some studies have reported associations between organic dust exposure and gastrointestinal (e.g., stomach) and respiratory problems among workers at material recovery and recycling facilities (Gladding et al., 2003; Ivens et al., 1997). The point should be made, however, that there are studies which have assessed exposure to ionizing radiation and radioactive materials among scrap metal-processing and -recycling workers (Lubenau and Yusko, 1998; Vearrier et al., 2009); these agents are recognized carcinogens for leukemia and thyroid cancer and could be related with significant excess risk of these tumors detected in the proximity of these installations by our study.

4.3. Installations for treatment of used oils and oily waste

These installations include the treatment (cleaning, re-refining, thermal fractionation, gasification and distillation) of all types of used oils and oily waste, and decontamination of equipment contaminated by PCBs, a group of organochlorine substances defined as oil waste by the European Waste Catalogue and Hazardous Waste List (Environmental Protection Agency, 2002). Among the substances released by these installations are recognized and suspected carcinogens, such as dioxins, arsenic, PAHs, benzene, chromium, nickel, lead, naphthalene or tetrachloroethylene.

To our knowledge, there are no epidemiologic or occupational studies of populations living near these types of installations. In this respect, therefore, our study is a pioneer in terms of analyzing the risk of dying due to cancer in the environs of such pollution sources and, indeed, detecting high excess risks for malignant tumors of the connective tissue (total population), pleura, skin, and stomach (men), and vulva and vagina (women). Some of these installations carry out oil re-refining, an activity which may involve significant levels of polycyclic aromatic compounds and PCBs derived from comingling used cutting oils with used engine and transformer oils (Hewstone, 1994). Long-term exposure to certain cutting fluids and mineral oils is known to be associated with an increase in certain occupational cancers, such as those of stomach and skin (DHHS (NIOSH), 1998; Mackerer, 1989). This could account for the excess risks observed in these tumors, given that they were only found in men, and would suggest a possible occupational exposure, assuming that workers' residence was homogenously distributed.

4.4. Installations for the regeneration of spent baths

In metal-scaling operations (i.e., immersion of metals, such as stainless steel, in acid baths to eliminate the layer of oxides formed on their surface after thermal treatments), a large quantity of effluents is discharged from spent baths in Europe every year (Frias and Perez, 1998). These effluents represent a serious environmental problem, as they are a type of waste that contains nitrates, fluorides, acids, and heavy metals (Singhal et al., 2006; Vijay and Sihorwala, 2003). In addition, treatment of such wastes gives rise to exposure to radioactive materials among workers at these plants (Donzella et al., 2007). Our study observed a statistically significant increase in the overall risk of dying from all cancers (men) in the vicinity of these installations, and particularly so in the case of malignant tumors of the stomach (total population), colon–rectum (men), liver (women) and ovary, and close to statistical significance in tumors of the lung and pleura (men).

5. Conclusion

Our results support the hypothesis of a statistically significant higher risk, among men and women alike, of dying from all cancers in towns situated near incinerators and hazardous waste treatment plants, and specifically, a higher excess risk in respect of tumors of the stomach, liver, pleura, kidney, and ovary. Furthermore, this is one of the first studies to analyze the risk of dying of cancer related with specific industrial activities in this sector at a national level, and to highlight the excess risk observed in the vicinity of incinerators and installations for the recycling of scrap metal and scrapping of ELVs, regeneration of spent baths, and treatment of oil and oily waste.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at http://dx.doi.org/10.1016/j.envint.2012.10.003.

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