ZERO WASTE EUROPE

Report

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Air Pollution from Waste Disposal: Not for Public Breath

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Tables and Figures

1. Introduction

This report addresses five case studies on incineration and co-incineration of waste in the European Union with regards to the accomplishment of the main Directives aimed at regulating air pollution.

Air emissions and air quality policies are among the older environmental policies. They have effectively made remarkable progress, particularly in the context of acid rain during the 80's[1]. However, as energy demand and energy prices increase, climate change continues to challenge industrial modes of production and consumption.

It is at the crossroads of the energy crisis (e.g. lack of fossil fuel reserves in the EU) and an increasing generation of waste that the incineration of waste as an option for disposal has gained momentum in the last decade. However, civil society has contested the incineration of waste from several perspectives[2].

First, from a health and environmental risk standpoint[3]. Despite the adoption of pollution abatement measures, the release of pollutants to air, soil and water is an unavoidable consequence of waste incineration. Among others, dioxins, heavy metals and particulate matter cause well-known respiratory diseases, cancer, immune system damage and reproductive and developmental problems[4].

Second, once incinerators are operating, a constant flow of waste (e.g. unsorted waste) is expected to be feeding these operations. Thus, they can potentially create a technological lock-in since further policy developments on waste prevention, separate collection, re-use and recycling will be discouraged.

[1] http://www3.epa.gov/region1/eco/acidrain/history.html
[2] http://www.zerowasteeurope.eu/2015/11/press-release-landfill-ban-a-false-path-to-a-circular-economy/
[3] http://www.bsem.org.uk/uploads/IncineratorReport_v3.pdf
[4] http://www.bsem.org.uk/recent-studies/the-health-effects-of-waste-incinerators/36/

Third, from the point of view of energy conservation, since according to life cycle analysis, incineration is less preferable than the re-use and recycling of materials.[5]

This report deals with pollutants released into the ambient air, as related to the limit values required by the EU Directives. Five case studies are addressed, navigating the most relevant dimensions of air pollution caused by incineration and co-incineration, namely emission limit values (e.g. values as measured at the point of emissions, for example a stack emissions), immission limit values (e.g. ambient air quality standards, values as measured by public monitoring devices), procedural conflicts in the issuing of permits and legitimacy conflicts when it comes to the valuation of alternative options for waste management.

[5] http://www.sciencedirect.com/science/article/pii/S0956053X0800439X

2. EU Policy framework overview concerning air pollution

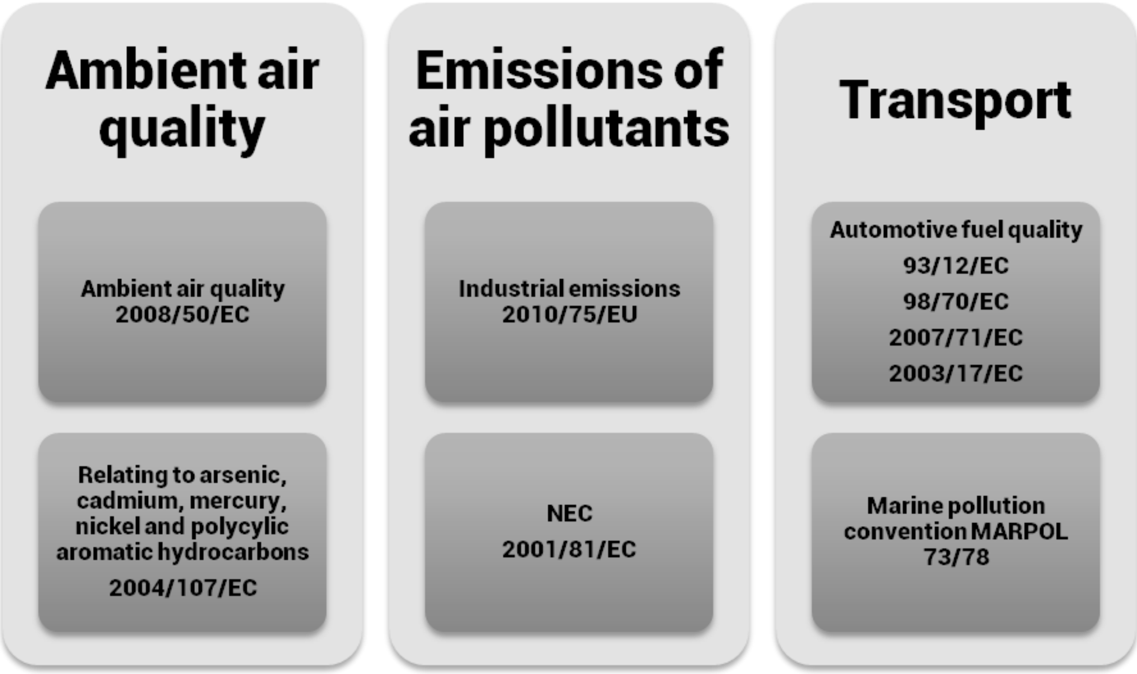
Air pollution policies have one of the longest backgrounds among environmental policies in Europe. The most recent packages of measures are the Thematic Strategy on Air Pollution[6] of 2005 and the Clean Air Policy Package[7] of 2013. These instruments set air quality targets for the period up to 2030.

Figure 1 shows the articulation of the European policies and Directives on air pollution. They focus in three main fields of action, namely ambient air quality (as measured by immission values), emissions of air pollutants, and transport. Fields 1 and 2 are the most relevant for the purpose of this work, since on the one hand waste incineration and co-incineration (e.g. cement kilns) are regulated (e.g. permits and limit values) under the legal frame of industrial emissions (Directive 2010/75/EU). On the other hand their effects on citizens is measured and regulated through the Directive 2008/50/EC on Ambient Air Quality (AQD). The following sections address the most relevant legislation on these two areas in order to set the benchmark for both emissions and immission limit values. These Directives set the quantitative, qualitative and procedural basis on which data from the case studies is checked against.

Moreover, the Waste Framework Directive (2008/98/EC[8]) is also taken into account, provided that it sets the so-called "waste hierarchy" criterion by which incineration is the second least preferable management option second only to landfill disposal.

[6] http://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:52005DC0446&from=EN
[7] http://ec.europa.eu/environment/air/clean_air_policy.htm
[8] http://ec.europa.eu/environment/waste/framework/

Figure 1. Articulation of European Directives in the field of air pollution.



Source: Own elaboration.

1.1. EU LEGISLATION ON EMISSIONS

Regulation on emissions addresses two main points: National Emissions Ceilings (NECs), and Industrial Emissions.

Regarding NEC, the Directive 2001/81/EC of the European Parliament and the Council on National Emission Ceilings for certain pollutants (NEC Directive) "*sets upper limits for each Member State for the total emissions in 2010 of the four pollutants responsible for acidification, eutrophication and ground-level ozone pollution (sulphur dioxide, nitrogen oxides, volatile organic compounds and ammonia), but leaves it largely to the Member States to decide which measures – on top of Community legislation for specific source categories - to take in order to comply*"[9]. This Directive is currently under revision[10] in order to set the targets to be met by 2020 and 2030.

For the purpose of this report, the regulation on industrial emissions is the most relevant since it set the limits to be met by individual industrial installations. In this field, legislation has evolved during the last decade resulting into an integrated framework as represented by the current Directive 2010/75/EU on industrial emissions (IED). The IED entered into force on 6 January 2011 and had to be transposed by Member States by 7 January 2013. On January 2014 the IED repealed and replaced previous legislation in place, namely Directive 2008/1/EC on integrated pollution prevention and control (IPPC), Directive 2000/76/EC on waste incineration, Directive 1999/13/EC on activities using organic solvents and Directives 78/176/EEC, 82/883/EEC and 92/112/EEC, concerning titanium dioxide production.

[9] http://ec.europa.eu/environment/air/pollutants/ceilings.htm
[10] http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52013PC0920

Given that the cases addressed in this study refer to the period prior to 2014, the IED, the Directive 2000/76/EC on waste incineration and the Directive 2008/1/EC on integrated pollution prevention and control would be the main pieces of legislation to be considered in order to determine if air breaches have occurred in individual industrial installations. Table 1 to 6 summarise the emissions limit values as expressed in these Directives[11]. As it can be observed, higher values for total dust and NO_x emissions are allowed for cement kilns although it has been pointed out that dust emissions might be effectively higher when fuels made from waste are used[12].

Apart from these limit values, the IED includes the requirements for permits and a core concepts such as "best available techniques" (BAT[13]) inherited from the Directive 2008/1/CE on Integrated Pollution Prevention and Control (IPPC Directive). BAT is defined in article 3(10) as: "the most effective and advanced stage in the development of activities and their methods of operation which indicates the practical suitability of particular techniques for providing the basis for emission limit values and other permit conditions designed to prevent and, where that is not practicable, to reduce emissions and the impact on the environment as a whole: 'techniques' *includes both the technology used and the way in which the installation is designed, built, maintained, operated and decommissioned; 'available techniques' means those developed on a scale which allows implementation in the relevant industrial sector, under economically and technically viable conditions, taking into consideration the costs and advantages, whether or not the techniques are used or produced inside the Member State in question, as long as they are reasonably accessible to the operator; 'best' means most effective in achieving a high general level of protection of the environment as a whole".*

This concept is relevant because emission limit values are set according to BAT, although no specific technology is prescribed (article 15.2) nor discarded in principle.

Table 1. Air emission limit values for waste incineration plants, daily averages.

Pollutant	**mg/Nm^3**
Total dust	10
Gaseous and vaporous organic substances, expressed as total organic carbon (TOC)	10
Hydrogen chloride (HCl)	10

[11] These values are referred to measurements made under the following conditions: Temperature of 273,15 K; Pressure of 101.3 kPa and after correcting for the water vapour content of the waste gases; Standardised at 11 % oxygen in waste gas, Except in case of incineration of mineral waste oil as defined in point 3 of Article 3 of Directive 2008/98/EC, when they are standardised at 3 % oxygen, and in the cases referred to in Point 2.7 of Part 6 of the IED

[12] http://www.aitecambiente.org/Portals/2/docs/pubblici/Documenti/Raccolta%20bibliografica/AITEC_CESISP_Stato%20arte%20-%20letteratura/Mokrzycki%202003_AFR_RE.pdf

[13] http://eippcb.jrc.ec.europa.eu/reference/

Pollutant	**mg/Nm^3**
Hydrogen fluoride (HF)	1
Sulphur dioxide (SO_2)	50
Nitrogen monoxide (NO) and nitrogen dioxide (NO_2), expressed as NO_2 for existing waste incineration plants with a nominal capacity exceeding 6 tonnes per hour or new waste incineration plants	200
Nitrogen monoxide (NO) and nitrogen dioxide (NO_2), expressed as NO_2 for existing waste incineration plants with a nominal capacity of 6 tonnes per hour or less	400

Source: Directive 2010/75/EU, Annex VI part 3.

Table 2. Air emission limit values for waste incineration plants, half-hourly averages.

Pollutant	**mg/Nm^3**
Total dust	30
Gaseous and vaporous organic substances, expressed as total organic carbon (TOC)	20
Hydrogen chloride (HCl)	60
Hydrogen fluoride (HF)	4
Sulphur dioxide (SO_2)	200
Nitrogen monoxide (NO) and nitrogen dioxide (NO_2), expressed as NO_2 for existing waste incineration plants with a nominal capacity exceeding 6 tonnes per hour or new waste incineration plants	400

Source: Directive 2010/75/EU, Annex VI part 3.

Table 3. Air emission limit values for waste incineration plants, over a sampling period of a minimum of 30 minutes and a maximum of 8 hours.

Pollutants	**mg/Nm^3**

Pollutants	mg/Nm^3
Cadmium and its compounds, expressed as cadmium (Cd)	0.05
Thallium and its compounds, expressed as thallium (Tl)	0.05
Mercury and its compounds, expressed as mercury (Hg)	0.05
Antimony and its compounds, expressed as antimony (Sb)	Total 0.5
Arsenic and its compounds, expressed as arsenic (As)	
Lead and its compounds, expressed as lead (Pb)	
Chromium and its compounds, expressed as chromium (Cr)	
Cobalt and its compounds, expressed as cobalt (Co)	
Copper and its compounds, expressed as copper (Cu)	
Manganese and its compounds, expressed as manganese (Mn)	
Nickel and its compounds, expressed as nickel (Ni)	
Vanadium and its compounds, expressed as vanadium (V)	

Source: Directive 2010/75/EU, Annex VI part 3. Directive 2000/76/EC Annex V. Note: These values are the double for those plants or which the permit to operate has been granted before 31 December 1996, and which incinerate hazardous waste only.

Table 4. Air emission limit values for waste incineration plants, over a sampling period of a minimum of 6 minutes and a maximum of 8 hours.

Pollutants	ng/Nm^3
Dioxins and furans	0.1

Source: Directive 2010/75/EU, Annex VI part 3. Directive 2000/76/EC Annex V.

Table 5. Air emission limit values for waste incineration plants for carbon monoxide (CO) in the waste gases.

Type of measurement	mg/Nm^3
Daily average value	50
Half-hourly average value	100
10-minute average value	150

Source: Directive 2010/75/EU, Annex VI part 3. Directive 2000/76/EC Annex V.

Table 6. Emission limit values for cement kilns co-incinerating waste.

Total emission limit values	mg/Nm3
Total dust (daily average value)	30
HCl (daily average value)	10
HF (daily average value)	1
NOx[14] (daily average value)	500
Cd + Tl (see notes)	0.05
Hg (see notes)	0.05
Sb + As + Pb + Cr + Co + Cu + Mn + Ni + V (see notes)	0.5
SO2 (daily average value)	50
TOC (daily average value)	10
	ng/Nm3
Dioxins and furans	0.1

Source: Directive 2010/75/EU, Annex VI part 4. Directive 2000/76/EC, Annex II. Notes: daily average values based on half-hourly averages. Average values over the sampling period of a minimum of 30 minutes and a maximum of 8 hours for heavy metals. Average values over the sampling period of a

[14] Until 1 January 2016, the competent authority may authorise exemptions from the limit value for NOx for Lepol kilns and long rotary kilns provided that the permit sets a total emission limit value for NOx of not more than 800 mg/Nm3

minimum of 6 hours and a maximum of 8 hours for dioxins and furans. All values are standardised at 10 % oxygen.

1.2. LEGISLATION ON AIR QUALITY

The main piece of legislation regarding ambient air quality is the Directive 2008/50/EC of the European Parliament and of the Council of 21 May 2008 on ambient air quality and cleaner air for Europe. It integrates the contents of Directives related to air quality as the Air Quality Framework Directive 96/62/EC[15] on ambient air quality assessment and management, Directive 1999/30/EC[16] relating to limit values for sulphur dioxide, nitrogen dioxide and oxides of nitrogen, particulate matter and lead in ambient air, Directive 2000/69/EC[17] relating to limit values for benzene and carbon monoxide in ambient air, the Directive 2002/3/EC[18] relating to ozone in ambient air, and includes additional limit values on $PM_{2.5}$.

The Air Quality Directive (AQD hereafter) sets the limit values as well as the procedures for measurement and validation (e.g. standards and statistical significance requirements) for a number of air pollutants such as ozone, sulphur dioxide, PM_{10}, $PM_{2,5}$, benzene, carbon monoxide and lead. Table 7 shows the most relevant limit values included in this Directive.

Table 7. Most relevant air quality limit values according to the Directive 2008/50/EC (AQD).

Pollutant	Type of measurement	Concentration
Sulphur dioxide	One hour	350 µg/m^3, not to be exceeded more than 24 times a calendar year
	One day	125 µg/m^3, not to be exceeded more than 3 times a calendar year
Nitrogen dioxide and oxides of nitrogen	One hour	200 µg/m^3, not to be exceeded more than 18 times a calendar year
	Calendar year	40 µg/m^3
Particulate matter (PM_{10})	One day	50 µg/m^3, not to be exceeded more than 35 times a calendar year
	Calendar year	40 µg/m^3
Lead	Calendar year	0,5 µg/m^3

[15] http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:31996L0062
[16] http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:31999L0030
[17] http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32002L0003
[18] http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32002L0003

Pollutant	Type of measurement	Concentration
Benzene	Calendar year	5 µg/m^3
Carbon monoxide	Maximum daily eight hour mean	10 mg/m^3

Source: Directive 2008/50/EC Annex XI B.

Other relevant legislation on ambient air quality is the Directive 2004/107/EC[19] relating to arsenic, cadmium, mercury, nickel and polycyclic aromatic hydrocarbons (PAHs) in ambient air, where target values for all pollutants except mercury are defined for the listed substances although for PAHs the target is defined in terms of concentration of *benzo(a)pyrene* since it is used as a general marker substance for PAHs. Only monitoring requirements are specified for mercury.

[19] http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32004L0107

3. Case Studies

Five case studies on waste incineration and co-incineration are addressed in this report: Lafarge cement plant in Montcada i Reixac (Barcelona, Spain), Lafarge cement plant in Trbovlje (Slovenia), Ivry waste incinerator in Paris (France), Dargavel waste incinerator in Scotland (United Kingdom) and Bavaria in Germany.

3.1 LAFARGE MONTCADA I REIXACH (BARCELONA, SPAIN)

Lafarge Cementos (cement plant), owned by Lafarge-Holcim group since 2014 and previously owned by Asland, is located close to the city of Barcelona, in the municipality of Montcada i Reixac. Montcada i Reixac has an area of 23.3 Km^2 and 34,394 inhabitants, and it is settled between the cliffs of the Litoral Mountains of Barcelona, close to the Besós River. The cement plant produces more than 500 tonnes of cement per day and employs close to 70 workers.

The neighbourhood association called *Can Sant Joan*[20], in coordination with other regional and national environmental platforms, has been the organisation through which demonstrations, research and legal actions have been carried out. The first protests asking for filters to be deployed occurred in 1975. In December 2006, after it was made public that the cement plant and the regional government (through the Catalan Water Agency) had plans to start using sludge, bone and meat meal and plastics as fuel,[21] they collected more than 6,000 signatures against this plan[22] and as a result it was delayed.

On April 20th 2008 the company received the environmental permit to use waste as fuel. Table 8 shows the types of waste allowed as fuel according to the original permit (permit number BA20060162[23], of April 29th 2008), and to the extension of that permit in 2011 (permit number BA20100180[24], of April 12th 2011). In July 2013, the Catalan Court of

[20] https://avvmontcadacansantjoan.wordpress.com/
[21] El Punt, November 9th 2006.
[22] Although this report is focused in air breaches, the protests have been also motivated by noise.
[23] http://www.prtr-es.es/informes/download.aspx?Document_id=6878/106
[24] http://bit.ly/1O53qM8

Justice revoked the original permit[25] due to formal defects during the process of public consultation, since the competences of the municipality related to noise, odour, vibrations, etc. had not been taken into account (e.g. they were not consulted in order to report on these issues). Lafarge appealed against the judgement and the Spanish Supreme Court rejected it in 2015[26]. Later in 2015, the Department of Environment repeated the process of public consultation as required by the sentence of the Supreme Court. On November 12th 2015, the plant once again obtained the environmental permit[27]. According to a press release from the neighbourhood association supported by their lawyer, the new issuing is still procedurally incorrect since the original environmental permit was declared null and void and therefore it cannot be amended or rectified. For a new permit to be issued, the whole process of permitting should be repeated[28].

Table 8. Types of waste included in the environmental permits for Lafarge Montcada cement plant.

Quantity	Code (ELW[29])	Description	Date of permit
Up to 40,000 t/year	02 03 01	Coffee grounds	2008
	19 08 05	Common sludge (excluding dredging spoils)	2008
	02 02 03	Animal Meal	2008
Up to 10,000 t/year	13 07 03	Chemical deposits and residues, namely biodiesel (out of standards) and glycerine	2008
Up to 20,000 t/year	17 02 01	Wood wastes	2008
	03 01 01	Wood wastes	2008
	03 01 05	Wood wastes	2008
	02 01 03	Garden waste	2008
Up to 30,000 t/year	19 12 10	Sorting residues rejected from mechanical treatment plants	2011

[25] http://www.elconfidencial.com/ultima-hora-en-vivo/2013-09-20/una-sentencia-tsjc-anula-licencia-de-impacto-ambiental-de-cementera-lafarge_47670/
[26] http://www.elconfidencial.com/ultima-hora-en-vivo/2015-07-30/supremo-ratifica-sentencia-que-prohibe-a-lafarge-fabricar-cemento-en-la-c-17_649946/ http://www.elconfidencial.com/ultima-hora-en-vivo/2015-07-30/supremo-ratifica-sentencia-que-prohibe-a-lafarge-fabricar-cemento-en-la-c-17_649946/
[27] http://www.elpuntavui.cat/territori/article/11-mediambient/914245-la-cimentera-de-montcada-obte-el-permis-ambiental.html
[28] Can Sant Joan neighbourshood association, personal communication on November 20th 2015
[29] European List of Wastes: http://ec.europa.eu/environment/waste/framework/list.htm

Source: Department of Environment and Housing, Generalitat de Catalunya.

These permits also establish the monitoring requirements in line with the Directive in place at that moment (2000/76/EC). These requirements (e.g. standards of measurement) are the continuous measuring, daily average values of:

- Particles: according to method UNE–EN 13284–1:2002
- HCl: according to method UNE-EN 1911
- HF: according to method ISO 15713
- NO_x: according to method UNE-EN 14792
- Total organic carbon: according to method UNE-EN 12619
- SO_2: according to method UNE-EN 14791

It also includes the manual measurement of:

- Heavy metals (Cd, Tl, Sb,As, Pb, Cr, Co, Cu, Mn, Ni, V): according to method UNE-EN 14385
- Dioxins and furans: according to method UNE-EN 1948
- Hg: according to method UNE-EN 13211

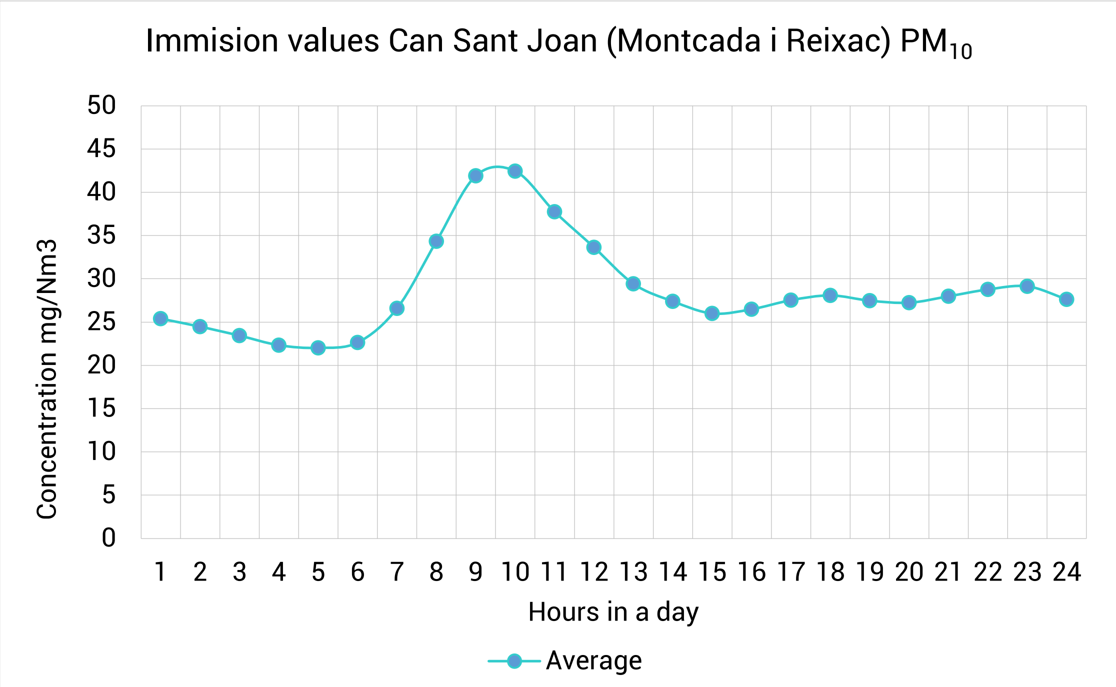
The neighbourhood association has carried out studies on immission values based on the measurement of the Catalan monitoring system (as required by the 2008 permit). High average (e.g. over 20mg/Nm^3) and maximum (e.g. over 500 mg/Nm^3) concentrations of PM_{10} were detected. According to the World Health Organization (WHO)[30] the guidelines for the annual concentration on PM_{10} as related to health risk are 20 µg/m^3, and 50 µg/m^3 as daily average. In tune, the AQD sets the limit values in surpassing 50 µg/m^3 during 35 days for daily averages, and 40 µg/m^3 for calendar year average (Table 7).

Figure 2 shows the hourly average values between June 2010 and October 2012. The distribution follows a pattern similar to traffic density (mostly condensed between 7am and 11am) although there was not any hour at which average values during the period had been below 20µg/m^3. The potential contribution of the cement plant can be easily identified during the night when traffic is not so relevant and the effect of the cement plan can be clearly observed.

Table 9 displays the annual average values in Montcada for three periods of one year, including one calendar year. All of them are well above (approximately 50%) the recommended values by the WHO although they do not reach the annual average limit value set in the AQD. During the whole period, average daily values over 50µg/m^3 were recorded 18 times, therefore surpassing the values pointed by the WHO but not the limit values set by the AQD.

[30] http://apps.who.int/iris/bitstream/10665/189524/1/9789241565080_eng.pdf?ua=1

Figure 2. PM_{10} hourly average values from June 2010 to October 2012.



Source: Department of Environment and Housing, Generalitat de Catalunya.

Table 9. Annual averages of PM_{10} concentration in Can Sant Joan, Montcada.

Period	PM_{10} Annual averages (mg/Nm^3)
14 June 2010 - 14 June 2011	29.16
1 January 2011 - 1 January 2012	28.99
8 October 2011 - 8 October 2012	28.02

Source: Department of Environment and Housing, Generalitat de Catalunya. Note: three periods of one year have been calculated according to the availability of data, taking the first and the last day as reference for the beginning and the end of the first and the last period respectively, plus one calendar day in between.

All in all, the case of Montcada highlights the relevance of the AQD limit values as compared to those recommended by the WHO for several pollutants. The limits in the case of the EU are set according to the so-called “best available techniques” whereas the WHO guidelines are based on epidemiological studies on health and environmental risk.

3.2 LAFARGE TRBOVLJE (SLOVENIA)

Lafarge's cement plant in Trbovlje (Slovenia) was established in 1876 close to abundant coal deposits, which provided the plant with a cheap source of energy. The factory is also connected to a 40 hectares of quarry of marly rock that supplies the plant with raw materials. In 1947, under the Yugoslavian government, it was nationalized. In 1972 a new kiln was put in production with a capacity of 1,000 tons of clinker per day. The company was sold in 2002 to the Lafarge group, which introduced automation for some of the production processes. They also added filters to the chimney after direct pressure from the government according to the reorganisation program.

The current nominal capacity of the plant is 1,400 tonnes of clinker per day. It employs 76 people although the number of workers has decreased since 2002.

After buying the plant in 2002, Lafarge started to use petroleum coke instead of fuel oil, which increased the emissions of benzene by 256% and Total Organic Carbon by 77%[31] In 2004, the first petition for stopping the use of coke was signed by 11,794 people, resulting into the establishment of the non-governmental organization *Eko krog* (Eco-cycle) in 2005, in order to provide a formal structure to the protests.

According to Eko krog, legal action started in 2006 after Lafarge initiated the process for legalizing the use of coke and obtaining the Integrated Pollution Prevention and Control (IPPC) permit for using waste as fuel. Although it is mandatory according to the Slovenian law, there was no public consultation during the IPPC issuing procedure. Therefore, those municipalities affected by the activity of Lafarge (e.g. Zagorje ob Savi) were not allowed to participate in the procedure. Only Uroš Macerl, farmer and president of Eko krog, was included in the IPPC issuing procedure due to the fact that he owned some land inside the 500 metres radius, which was recognised by authorities as official area of influence (the study was performed by EIMV institute and paid by Lafarge).

The government issued the first IPPC permit in 2009 for waste incineration (permit number 35407-104/2006-195 of July 23rd) and the second in 2014 for petroleum coke (permit number 35407-104/2006-391). Eko Krog took these permits to the court. Table 10 shows the list of wastes allowed for burning according to the first permit.

In February 2015, the European Commission took Slovenia to court "*for its failure to license industrial installations that are operating without permits. Such permits should only be issued if a number of environmental criteria are met. In 2010 the Court ruled that Slovenia was failing in its obligation to ensure that all installations operate in line with EU rules on pollution prevention and control. Four years after that judgement, a major cement factory is still operating without the necessary permit, and potentially endangering citizens' health. The Commission is asking for a daily penalty payment of EUR 9,009 from today until the obligations are fulfilled and a lump sum of EUR 1,604,603*". [32]

[31] Eko krog, personal communication
[32] http://europa.eu/rapid/press-release_IP-15-4492_en.htm

According to Eko Krog the plant was shut down in March 2015[33]. In July 2015, Lafarge appealed the shutdown but the appeal was rejected in July by the Ministry of the Environment.

In this case, although Eko krog was mainly concerned about heavy metals, benzene, total organic compounds (TOC), NO_x, and dust, it was the odour that mobilized the most people. Particularly after several filters were removed, which intensified these problems. In legal terms, formal defects in the issuing of the permit (e.g. public consultation) were the grounds for legal action.

Table 10. Types of waste allowed for burning in permit 35407-104/2006-195 of July 23rd for Lafarge cement Trbovlje.

Type of waste	ELW code	Description	Annual Quantity (t)
Hazardous waste	19 12 10	Combustible waste – waste plastics	15,000
	16 01 03	End-of-life tyres	6,000
Non-Hazardous waste	13 01 10	Mineral-based non-chlorinated hydraulic oils	3,000
	13 01 11	Synthetic hydraulic oils	300
	13 01 13	Other hydraulic oils	300
	13 02 05	Mineral-based non-chlorinated engine, gear and lubricating oils	5,000
	13 02 06	Synthetic engine, gear and lubricating oils	300
	13 03 07	Mineral-based non-chlorinated insulating and heat transmission oils	400
	13 03 08	Synthetic insulating and heat transmission oils	300
	13 03 10	Other insulating and heat transmission oils	100
	13 04 01	Bilge oils from inland navigation	100
	13 04 02	Bilge oils from jetty sewers	100

[33] http://www.ekokrog.org/2015/07/15/mop-zavrnilo-lafargevo-pritozbo/#more-4222

13 04 03	Bilge oils from other navigation	500
13 05 06	Oil from oil/water separators	1,000
13 08 02	Other emulsionns	300

Source: Zero Waste Italy.

3.3 BAVARIAN INCINERATORS AND CEMENT PLANTS (GERMANY)

The region of Bavaria is a federal state of Germany located in the south-eastern part of the country. It is 70,549 km^2 and has a population of 12.6 million inhabitants, which makes it the largest and the second most populated region of Germany.

Within the region, six cement plants operate and all six of them have an authorisation permit for the co-incineration of waste. These cement plants are Burglengenfeld, Harburg, Karlstadt, Rohrdorf, Solnhofen and Triefenstein Lengfurt.

According to the State Ministry of Environment and Consumer Protection, the following quantities of waste were co-incinerated during 2012 and 2013 in cement plants:

Table 11. Types and quantities of waste co-incinerated in 2012 and 2013 in Bavarian in cement plants.

Type of waste	2012 (t)	2013 (t)
Sewage sludge	41,700	42,900
Hazardous waste (solvents, oils, roofing cardboard)	50,500	46,300
Non-hazardous waste (tyres, industrial waste, paper, animal meal)	589,600	583,700

Source: State Ministry of Environment and Consumer Protection.

The emission limit values are set in the Seventeenth Ordinance for the Implementation of the Federal Pollution Control Act (Order on the incineration and co-incineration of waste - 17. BImSchV[34]) of 2 of May of 2013 (Table 12). As it can be noted, emission limit values are higher for cement plants. These differences on limit values are justified, according to the State Ministry, since different technologies for the burning processes require different limits.

According to the State ministry of Environment and Consumer Protection, in response to Malka Freie Wähler on 19th May 2014, since 2005 air breaches regarding dust, NO_x, SO_x, Hg, HCl and benzene have been reported (Table 13).

[34] http://www.gesetze-im-internet.de/bundesrecht/bimschv_17_2013/gesamt.pdf

Table 12. Emissions limit values in Bavaria for waste incineration plants and co-incineration cement plants.

	Waste incineration plants (mg/m³)			Equipment for the production of cement clinker or cement (mg/m³)		
Pollutant	**Daily average values**	**Half-hourly average values**	**Annual Mean**	**Daily average values**	**Half-hourly average values**	**Annual Mean**
Dust	5	20	-	10	30	-
Nitrogen oxides	150	400	100 *	200 *	400 *	200 *
Ammonia	10	15	-	30	60	-

*Source: State Ministry of Environment and Consumer Protection. Note: * apply from 01.01.2019; so-called mixed limits for cement plants up to the 31.12.2018 (max. daily average values 500 mg/m³) according to the 17th BImSchV i. d. F. of the 14.08.2013, as last amended by regulation from January 27th, 2009.*

Moreover, 15 incinerators[35] for non-hazardous waste and 6 for hazardous waste are sited within the State. They are Augsburg, Bamberg, Burgau[36], Burgkirchen, Coburg, Geiselbullach, Ingolstadt, Kempten, München-Nord, Nürnberg, Rosenheim, Schwandorf, Schweinfurt, Weissenhorn and Würzburg for non-hazardous waste and Burghausen, Ebenhausen, Gendorf, Gersthofen, Kelheim and Trostberg for hazardous waste. Data for 2011 show that for some of these plants, exceedances have occurred:

Table 13. List of incinerators burning non-hazardous waste and exceedances in emissions limit values in 2011

Incinerator	Exceedances in limit values in 2011
Augsburg	SO_2, CO
Bamberg	CO, Dust
Burgau	SO_2, HCl, NOx, Dust, CO, Hg
Coburg	TOC, CO

[35] Up to 2011, there were 16 operative incinerators. Landshut incinerator was shut-down in 2011.
[36] This is a pyrolysis plant.

Geiselbullach	SO_2, HCl, CO, Hg, TOC
Ingolstadt	SO_2, NOx, Dust, TOC, CO
Kempten	SO_2, NOx, Dust, TOC CO
München-Nord	SO_2, NOx, CO
Nürnberg	Dust, CO
Rosenheim	CO, NH_3
Schwandorf	SO_2, HCl, Dust, CO
Schweinfurt	SO_2, NOx, TOC, CO
Weissenhorn	SO_2, Dust, CO
Würzburg	SO_2, HCl, CO, Hg

Source: dr Hartmut Hoffmann

Although no legal breaches were found, the exceedances in TOC and CO values might entail emissions of dioxins and furans[37], which are not measured by continuous monitoring. In this case, the issue of emission limit values set in the permits as compared to the guidelines published by the WHO arises again. Furthermore, the allowance for cement plant to release higher concentrations of pollutants than incinerators is also acknowledged and justified by the authorities based on technological arguments.

3.4 DARGAVEL WASTE INCINERATOR, DUMFRIES (SCOTLAND, UK)

Scotgen (Dumfries) Ltd is a continuous batch incinerator with energy recovery located in Dumfries (Scotland), for three years considered Scotland's worst polluter according to the Scotland Environmental Protection Agency (SEPA)[38].

The plant was permitted in May 2009. By the end of that year, clean wood and municipal waste were commissioned although incineration stopped between January and March 2010 due to technical problems with combustion which lead to several modifications in the plant. Despite these changes, the problems remained so that the plant was closed again in April 2011 for approximately one year in order to redesign and install new boiler systems. In February 2013 the permit was varied to require the proper functioning of the plant by June 2013.

[37] https://www.energinet.dk/SiteCollectionDocuments/Danske%20dokumenter/Forskning%20-%20PSO-projekter/FU5731%20-%20Final%20report.pdf
[38] http://www.heraldscotland.com/news/13123975.Revealed__Scotland_s_worst_polluters/

The incinerator had its license revoked by SEPA on 23 August 2013 after hundreds of toxic pollution breaches and a major fire in July 18th 2013, which left up to 800-tonnes of waste not being properly burnt. The reasons, as publicised in the notice issued by SEPA[39], are:

- Persistent non-compliance with the requirements of the permit
- Failure to comply with an enforcement notice
- Failure to maintain financial provision and resources to comply with the requirements of the permit
- Failure to recover energy with a high level of efficiency[40]

Besides, the revocation notice also requires several steps to be taken in order to restore a satisfactory state of the site.

During the first operational period of the incinerator (December 2009 – April 2011), SEPA[41] reported the following incidents:

- 45 noise complaints
- 38 by-pass stack activations
- 200 reported emission limit breaches (mainly short-term temperature and O_2 levels)
- 2 dioxin emission breaches
- 100 notifications of short-term exceedances.

Once the activity was restarted (June 2013), more incidents occurred:

- 19 noise complaints
- 50 by-pass stack activations
- 3 low temperature alerts
- 23 low O_2 alerts
- 6 dioxin emission breaches
- 1 plant communications failure
- 2 failures of the daily HCl limit
- 1 failure of daily NO_x limit

[39] http://media.sepa.org.uk/media-releases/2013/sepa-revokes-scotgen-dumfries-limiteds-permit/
[40] According to Shlomo Dowen (UK Without Incineration Network), "*the Dargavel facility was shut down without ever having exported any electricity to the grid* : http://www.hucknalldispatch.co.uk/news/waste-incineration-debunking-the-myths-1-6451958#ixzz3r4wHYAfF
[41] http://www.ukwin.org.uk/files/pdf/sepa_dargavel_june_2013.pdf

- 2 failure of the heavy metals limit
- 1 complaint of flies
- 1 incident of accepting waste outside operational hours
- 2 incidents of process building doors being left open for prolonged periods
- 2 incidents of dark smoke emissions from the bypass stacks.

In addition, SEPA reported emission limit values breaches, which did not result in permit breaches. However, it was the following incidents that led to plant closure:

- 6 dioxin limit values breaches in 2012
- Faulty temperature controllers caused a burst

In March 2014, the company Rank Recycling Scotland bid to restart the plant and applied for a new pollution prevention and control permit, after the transfer of the previous permit, as held by Scotgen, was denied. In May 2014, SEPA confirmed no application for PPC permits had been sent although "*Rank Recycling Scotland Ltd has indicated it is their intention to modify the plant design and submit an application*"[42].

In this case, air breaches have been repeatedly reported and acknowledged by the authorities. The malfunctioning of this plant is mostly related to its initial design.

3.5 IVRY INCINERATOR (PARIS, FRANCE)

The Ivry-Paris XIII incinerator, located at the southeast of the city of Paris, is the largest incineration plant in France. It was originally commissioned in 1969 and currently covers 38% of the processing capacity of the municipal association for waste management (Syndicat Intercommunal de Traitement des Ordures Ménagères de l'Agglomération Parisienne) carrying out the incineration of waste from 12 neighbourhoods and 14 "communes" of Paris. It serves more than one million inhabitants, processing up to 730,000 tonnes of waste in ten parallel process lines and delivering power equivalent to 100,000 households heating.

According to the last annual report published by SYCTOM[43] (the owners of the plant), no emissions breaches were registered during 2013. However, according to 3R[44], immission measurements taken in a nearby school in 2013 showed high values of dioxins and furans (up to eleven times those reported by the plant). The local authorities (Airparif), based on measurements carried out during six weeks, have reported estimated annual concentrations of $PM_{2.5}$ and PM_{10} of 18 and 25 mg/Nm^3 respectively in 2014[45]. These values are compliant with EU limit values although they surpass the AQG of the WHO.

42 https://www.whatdotheyknow.com/request/212361/response/522343/attach/3/attachment.pdf
43 http://www.sita.fr/wp-content/uploads/2015/01/20141118_DIP_20131.pdf
44 https://drive.google.com/file/d/0B_bgBW25wNeiX1JhWXZNRFFCRFU/view
45 http://www.airparif.asso.fr/_pdf/publications/rapport-uiom-ivry-sur-seine-140606.pdf

The plant is planned to be reconstructed between 2017 and 2023 through a €1,575 million project signed in February 2015 (to be paid through waste charges) to be carried out by Suez Environment. The project includes a reduction of the incineration capacity by half, plus the deployment of a mechanical biological (plus biomethanisation) plant.

Protests have arisen led by 3R, which has sent a formal appeal to the Paris Administrative Court based on the following points:

- Contract duration is 23 years (including construction and exploitation). It is considered too long for a public contract.

- The costs do not correspond with the technology to be implemented. The technical score achieved in the evaluation process (64%) can be considered poor as compared to other options.

According to 3R, should low performance of separate collection in the region be improved (only 3% of households have access to separate collection of bio-waste, being these 40% of total waste produced), the plant update would be unnecessary and so the associated risks (e.g. precedent fires in mechanical biological treatment plants in France) and foreseeable inconveniences (e.g. odour).

Two associations, namely 3R[46] and Zero Waste France[47], have presented an alternative, B'OM project[48], where significant increases of separate collection and reductions in the rejects of packaging waste are expected. This plan foresees total waste generation to decrease from 2 million tonnes in 2014 to 1.25 million tonnes. The cost of this plan is estimated to be €200 million (one order magnitude less than the plant update project).

This case illustrates the existence of the alternatives to incineration in the broader context of waste management policies and public investment.

46 http://collectif3r.blogspot.com.es/
47 http://www.zerowasteeurope.eu/
48 http://www.planbom.org/

4. Discussion of EU Directives shortages

The IED and the AQD show a number of issues that, in the context of waste incineration and co-incineration might be controversial. In fact, the capacity of the EU Directives for protecting human life and the environment is often challenged by local groups through protest and legal actions, as exposed in the previous section. In the light of the cases addressed, several aspects of these Directives are highlighted and discussed in the next sections.

4.1. ISSUES ON AMBIENT AIR QUALITY

The main source of concern is on the quantitative limit values set by the AQD (see Table 7) as compared to the air quality guidelines (AQG) of the World Health Organization on air quality[49], since these guidelines point to lower values than those required by the AQD for several pollutants (see table 14 for a comparison). More specifically:

- The AQG for the annual average concentration of PM_{10} (20 $\mu g/m^3$) is a half of the concentration required by the AQD (40 $\mu g/m^3$). The current EU level corresponds to the medium point between the so-called Interim target-2 and target-3 of the WHO. This concentration is associated to a risk of increasing cardiopulmonary and lung cancer mortality.

- In the case of $PM_{2.5}$ the EU annual average limit (25 $\mu g/m^3$) more than doubles the AQG. At the AQD limit value, the WHO states a risk of premature mortality of between 4 and 13%.

- For SO_2, the WHO states "a prudent precautionary approach to a value of 20 ng/m^3" for the daily average whereas the EU limit values is set in 125 $\mu g/m^3$ not to be surpassed more than 3 times in a calendar year. No further indications are given regarding daily averages. Furthermore the WHO stressed the relevance of shorter exposures (10 minutes) for which no limits are set by the EU.

[49] http://apps.who.int/iris/bitstream/10665/69477/1/WHO_SDE_PHE_OEH_06.02_eng.pdf

- Ozone concentrations (measured as 8-hour mean concentration) as stated by the AQG should be below 100 µg/m^3. The EU standards sets a limit value of 120 µg/m^3 during 25 days averaged over three years.

Regarding other relevant pollutants such as arsenic, nickel and polycyclic aromatic hydrocarbons, the limit value set by the EU Directives cannot be compared to the AQG value provided by the WHO. In these cases, the risk of exposure to these pollutants is measured as probability of diminished life expectancy (see table 14).

Apart from differences between the AQG and the EU standards, and the lack of reference values in the Directive for some pollutants, the AQD, Annex I, sets the data quality standards for air quality measurements. These quality standards assume an additional range of acceptable uncertainty in the measurements, which in practice might allow higher actual concentrations to occur.

Taking these issues into account, a question on how these values should be set arises. The AQD assumes several deviations from the AQG, which in turn implies assuming a certain degree of health risk (e.g. measured as probability of premature death). Being public health at stake, it would be advisable that the grounds on which these limit values are set would be publicly debated whenever they surpass the values recommended by international accredited organizations such as the WHO. Moreover, they should be regularly reviewed and put in the context of the current local air quality status and available alternatives, in a proper application of the Precautionary Principle[50]. There are examples of a proper application of the Precautionary Principle*, inter alia* for asbestos[51].

This kind of issues have been also addressed by the “Post-Normal science" approach[52].: *“[t]he insight leading to Post-Normal Science is that in the sorts of issue-driven science relating to environmental debates, typically facts are uncertain, values in dispute, stakes high, and decisions urgent"*. The most relevant conclusion from this approach is a procedural point, according to which "*[t]he contribution of all the stakeholders in cases of Post-Normal Science is not merely a matter of broader democratic participation. For these new problems are in many ways different from those of research science, professional practice, or industrial development. Each of those has its means for quality assurance of the products of the work, be they peer review, professional associations, or the market. For these new problems, quality depends on open dialogue between all those affected. This we call an "extended peer community", consisting not merely of persons with some form or other of institutional accreditation, but rather of all those with a desire to participate in the resolution of the issue"*.

Overall, the current limit values operate between risk and uncertainty for human health and the environment (e.g. immission levels and health risk). In this context, public consultation and participation would be referred to the evaluation of alternatives for waste management.

[50] http://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=URISERV:l32042&from=EN
[51] http://unesdoc.unesco.org/images/0013/001395/139578e.pdf
[52] http://www.nusap.net/sections.php?op=viewarticle&artid=13

Table 14. Limit values at the EU level as compared to guidelines from the World Health Organization.

Pollutant	Period	Limit value Directive 2008/50/CE	Permitted exceedances (per year)	Guidelines WHO
$PM_{2.5}$	1 year	25 µg/m^3	n/a	10 µg/m^3
	24 h	-	-	25 µg/m^3
SO_2	10 min	-	24	500 µg/m^3
	1 h	350 µg/m^3	-	-
	24 h	125 µg/m^3	3	20 µg/m^3
NO_2	1 h	200 µg/m^3	18	200 µg/m^3
	1 year	40 µg/m^3	n/a	40 µg/m^3
PM_{10}	24 h	50 µg/m^3	35	50 µg/m^3
	1 year	40 µg/m^3	n/a	20 µg/m^3
Ozone	Max daily 8 h mean	120 µg/m^3	25 days averaged over 3 years	100 µg/m^3
As	1 year	6 ng/m^3	n/a	At an air concentration of 1 µg/m3 an estimate of lifetime risk is 1.5 × $10E^{-3}$
Cd	1 year	5 ng/m^3	n/a	5 ng/m^3
Ni	1 year	20 ng/m^3	n/a	Incremental risk of 3.8 × 10E−4 can be given for a concentration of nickel in air of 1 µg/m^3.
PAHs	1 year	1 ng/m^3	n/a	A unit risk for Benzene(a)Pyrene as indicator air constituent for PAHs is estimated to be 8.7 × 10−5 per ng/m3

Sources: ttp://apps.who.int/iris/bitstream/10665/69477/1/WHO_SDE_PHE_OEH_06.02_eng.pdf and http://www.euro.who.int/__data/assets/pdf_file/0005/74732/E71922.pdf?ua=1.

4.2. ISSUES ON INDUSTRIAL EMISSIONS

A first relevant point regarding the IED is the core concept of "best available technique" (BAT).

The introduction of the Directive, point 16, reads: "*In order to take into account certain specific circumstances where the application of emission levels associated with the best available techniques would lead to **disproportionately high costs compared to the environmental benefits,** competent authorities should be able to set emission limit values deviating from those levels. Such deviations should be based on an assessment taking into account well-defined criteria. The emission limit values set out in this Directive **should** not be exceeded. In any event, no significant pollution should be caused and a high level of protection of the environment taken as a whole should be achieved*." This implies that best available technique relies upon qualitative economic criteria.

Article 15.4 reads: "[…] *the competent authority may, in specific cases, set less strict emission limit values. Such a derogation may apply only where an assessment shows that the achievement of emission levels associated with the best available techniques as described in BAT conclusions would lead to disproportionately higher costs compared to the environmental benefits due to: (a) the geographical location or the local environmental conditions of the installation concerned; or (b) the technical characteristics of the installation concerned*".

Therefore, if limit values depend on BAT and those are defined according to economic criteria, the latest play a central role in setting limit values. This has several implications. First, that in the event of a dispute about BAT, both financial cost and environmental benefits should be measured and compared. Environmental valuation for decision-making has proven controversial and with plenty of epistemological and procedural shortages since it implies the choice of a language of valuation and an allocation of resources to future generations[53]. Secondly, the meaning of "disproportionately" remains qualitative. Third, it states that the decision on specific derogations corresponds to the national authorities.

Article 59.2 also foresee a situation where the limit values can be exceeded: "*[…] where the operator demonstrates to the competent authority that for an individual installation the emission limit value for fugitive emissions is not technically and economically feasible, the competent authority may allow emissions to exceed that emission limit value provided that significant risks to human health or the environment are not to be expected and that the operator demonstrates to the competent authority that the best available techniques are being used*". Again, qualitative criteria (e.g. significant risk) are employed in order to evaluate whether limit values could be exceeded, in the event it is not economically feasible to achieve them.

[53] http://www.redibec.org/archivos/revista/articulo7.pdf

Furthermore, emission breaches are evaluated based on continuous monitoring data carried out and reported by the companies, plus a number of annual inspections. Filters and their continuous monitoring systems are currently paid for and managed by the cement plants and incinerators, which makes it more difficult to find air breaches.

The process of public consultation for permit issuing has resulted into a source of conflict in itself and current regulation allow for situations such as the process in Slovenia, where the nearby municipalities were not included. In Montcada, the municipal government took Lafarge to the court because their competences were ignored during the issuing of the permit. After winning the case, the cement plant continued operating.

4.3. FURTHER CONSIDERATIONS

Besides issues related to air pollution, there are at least two additional relevant points to be mentioned regarding incineration activities.

First, in the context of waste management options, there is a large margin to further develop and prioritise the higher tiers of the waste hierarchy, namely prevention, re-use and recycling. It has been demonstrated[54] that high levels of separate collection and recycling (around 75%) are achievable in Europe. Therefore incineration would not be required to comply with Directive 1999/31/EC on the landfill of waste, which set reduction targets for total waste landfilled. Moreover, by fostering incineration, the potential contribution of waste management to a transition towards a low carbon economy might be missed[55].

Second in economic terms, cement plants receive a triple dividend from waste incineration activities[56]. First, they get paid as waste managers by the competent authorities (e.g. 10 euros per tonne of waste in the case of Lafarge Montcada). Second, they save the corresponding quantity of fossil fuels substituted by waste, and therefore their costs. Third, they can trade emissions permits corresponding to those fossil fuel savings, some of which have been assigned to these facilities at no cost. In practice, this implies that taxpayers are effectively supporting waste incineration and the associated allocation of health and environmental risks.

[54] http://zerowasteeurope.eu/zerowastecities.eu/
[55] http://www.zerowasteeurope.eu/downloads/the-potential-contribution-of-waste-management-to-a-low-carbon-economy/
[56] http://www.greenpeace.org/espana/Global/espana/report/contaminacion/cdr290512.pdf

5. General conclusions

This report presents a general review of EU Directives on air quality and emissions and five case studies on conflicts between citizen and installations devoted to the incineration or co-incineration of waste (e.g. cement plants).

Incineration activities release pollutants to ambient air. These pollutants, at certain concentrations, lead to health and environmental issues, as the World Health Organization has acknowledged. Several European Directives have addressed the abatement and control of these pollutants both from the point of view of the polluters through the IED, and from of the point of view of citizens through the AQD. In addition, the Waste Framework Directive has set the order of priorities for waste management options, amongst which incineration (either dedicated plants or cement kilns) with energy recovery is only preferred to landfill disposal.

The cases of cement plants in Spain, Slovenia and Germany and incinerators in the UK, Germany and France have been addressed. Although the protests in each case are based on different grounds and motivations, the issues of air pollution, health risk, procedural defects and conflict on legitimacy are common to all these cases.

The current design of the EU legal framework allows for immission limit values that face an unavoidable allocation of health and environmental risks to those citizens living nearby incineration and co-incineration activities. This entails an environmental justice issue since very often, nearby municipalities are populated by low income families and immigrants[57].

Although emissions limit values are regulated, significant legal space exists for more stringent emission and immission values (e.g. WHO guidelines). More specifically, the core concept of "best available technique" links emissions limit values directly to the economic costs of technologies. Therefore, emission limit values are conditioned by the affordability of cleaner technologies so that innovation in the field of health and environmental protection is constrained.

[57] http://www.tandfonline.com/doi/abs/10.1080/09640568.2012.749395

As a common trait, the organizational skills of civil society have shown key for monitoring and limiting the impact of incineration activities, based on a variety of legal, health and environmental arguments.

http://www.zerowasteeurope.eu/

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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 mid-point 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:

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

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

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

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

$$\begin{aligned} &h_i \sim Normal(\theta, \tau_h) \\ &b_i \sim Car.Normal(\eta_i, \tau_b) \\ &\tau_h \sim Gamma(\alpha, \beta) \\ &\tau_b \sim Gamma(\gamma, \delta) \end{aligned}$$

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.

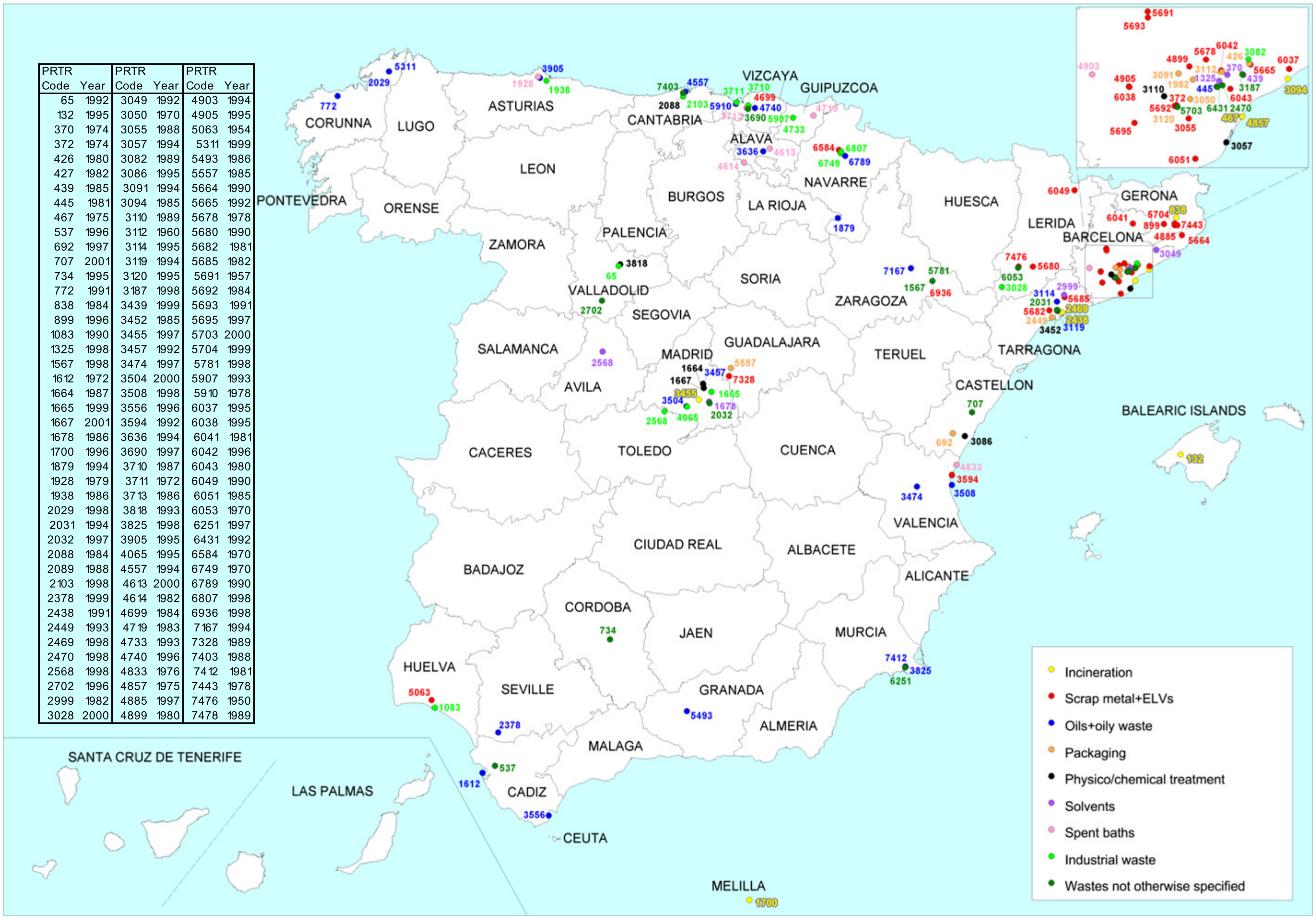

Fig. 1. Geographic distribution of Spanish-based incinerators and hazardous waste treatment installations.

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 $\geq$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]	BYM model 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		Industrial activity[a]	PRTR code		T[b]	Obs[c]	BYM model	
					RR[d]	95% CrI[e]						RR[d]	95% CrI[e]
Bladder cancer							Myeloma						
		Men	2	97	**1.68**	**1.03–2.56**			Men	4	23	1.73	0.78–3.34
		Women	2	19	0.85	0.33–1.81			Women	4	31	**2.24**	**1.05–4.32**
9	6053	Total	2	116	1.47	0.92–2.19	9	7478	Total	5	31	**1.91**	**1.11–3.04**
		Men	2	97	**1.67**	**1.01–2.55**			Men	5	20	**2.25**	**1.09–4.09**
		Women	2	19	0.86	0.33–1.81			Women	5	11	1.56	0.64–3.09
Brain cancer							Leukemia						
1	2438	Total	2	69	1.14	0.70–1.79	2	372	Total	4	42	**1.59**	**1.03–2.30**
		Men	2	27	0.78	0.37–1.66			Men	4	22	1.27	0.72–2.05
		Women	2	42	**2.05**	**1.01–3.72**			Women	4	20	**2.28**	**1.16–3.98**
2	372	Total	4	30	1.49	0.89–2.31	2	3055	Total	5	59	**1.58**	**1.08–2.23**
		Men	4	13	0.99	0.47–1.78			Men	5	36	1.56	0.96–2.38
		Women	4	17	**2.59**	**1.17–4.92**			Women	5	23	1.69	0.90–2.87
2	4699	Total	6	111	1.42	0.92–2.10	2	3594	Total	10	50	**1.63**	**1.06–2.40**
		Men	6	59	**1.90**	**1.04–3.20**			Men	10	28	1.70	0.96–2.79
		Women	6	52	1.12	0.59–1.90			Women	10	22	1.65	0.84–2.88
2	5692	Total	3	27	1.43	0.84–2.25	2	4699	Total	6	136	1.24	0.82–1.80
		Men	3	12	0.98	0.45–1.78			Men	6	77	0.96	0.58–1.51
		Women	3	15	**2.50**	**1.09–4.86**			Women	6	59	**1.97**	**1.01–3.49**
3	5910	Total	3	16	**2.25**	**1.11–3.95**	2	5680	Total	5	16	**2.31**	**1.18–3.95**
		Men	3	8	2.63	0.94–5.52			Men	5	10	**2.83**	**1.16–5.51**
		Women	3	8	2.05	0.73–4.36			Women	5	6	1.92	0.63–4.13
4	3050	Total	3	46	**1.60**	**1.02–2.40**	2	5692	Total	3	39	**1.60**	**1.03–2.35**
		Men	3	25	1.36	0.76–2.24			Men	3	20	1.26	0.69–2.05
		Women	3	21	**2.14**	**1.03–3.92**			Women	3	19	**2.37**	**1.19–4.18**
7	2088	Total	3	37	**1.91**	**1.02–3.24**	2	6051	Total	3	81	1.28	0.85–1.86
		Men	3	22	1.97	0.84–3.86			Men	3	43	1.01	0.60–1.60
		Women	3	15	1.88	0.68–4.12			Women	3	38	**2.02**	**1.02–3.67**
8	3710	Total	6	111	1.42	0.92–2.10	3	6789	Total	2	147	**2.11**	**1.13–3.65**
		Men	6	59	**1.90**	**1.04–3.20**			Men	2	85	**2.87**	**1.25–5.82**
		Women	6	52	1.12	0.59–1.90			Women	2	62	1.57	0.63–3.27
8	3711	Total	4	25	**2.42**	**1.31–4.03**	4	3120	Total	5	49	**1.60**	**1.07–2.29**
		Men	4	14	**3.42**	**1.47–6.66**			Men	5	25	1.25	0.72–1.97
		Women	4	11	1.78	0.70–3.60			Women	5	24	**2.37**	**1.26–4.05**
9	2089	Total	3	43	**1.92**	**1.03–3.28**	8	3710	Total	6	136	1.24	0.82–1.80
		Men	3	22	1.52	0.62–3.07			Men	6	77	0.96	0.58–1.51
		Women	3	21	2.47	0.94–5.31			Women	6	59	**1.97**	**1.01–3.49**
9	7403	Total	3	43	**1.92**	**1.03–3.28**	9	5703	Total	5	49	**1.60**	**1.07–2.29**
		Men	3	22	1.52	0.62–3.07			Men	5	25	1.25	0.72–1.97
		Women	3	21	2.47	0.94–5.31			Women	5	24	**2.37**	**1.26–4.05**
							9	6053	Total	2	109	**1.65**	**1.00–2.51**
Thyroid cancer									Men	2	57	1.69	0.89–2.88
1	467	Total	3	21	1.11	0.38–2.59			Women	2	52	1.78	0.97–3.00
		Men	3	6	0.66	0.13–2.18	9	7478	Total	5	59	**1.58**	**1.08–2.23**
		Women	3	15	**2.05**	**1.52–6.14**			Men	5	36	1.56	0.96–2.38
1	4857	Total	3	21	1.10	0.38–2.57			Women	5	23	1.69	0.90–2.87
		Men	3	6	0.65	0.14–2.14							
		Women	3	15	**2.04**	**1.49–6.13**							

[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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